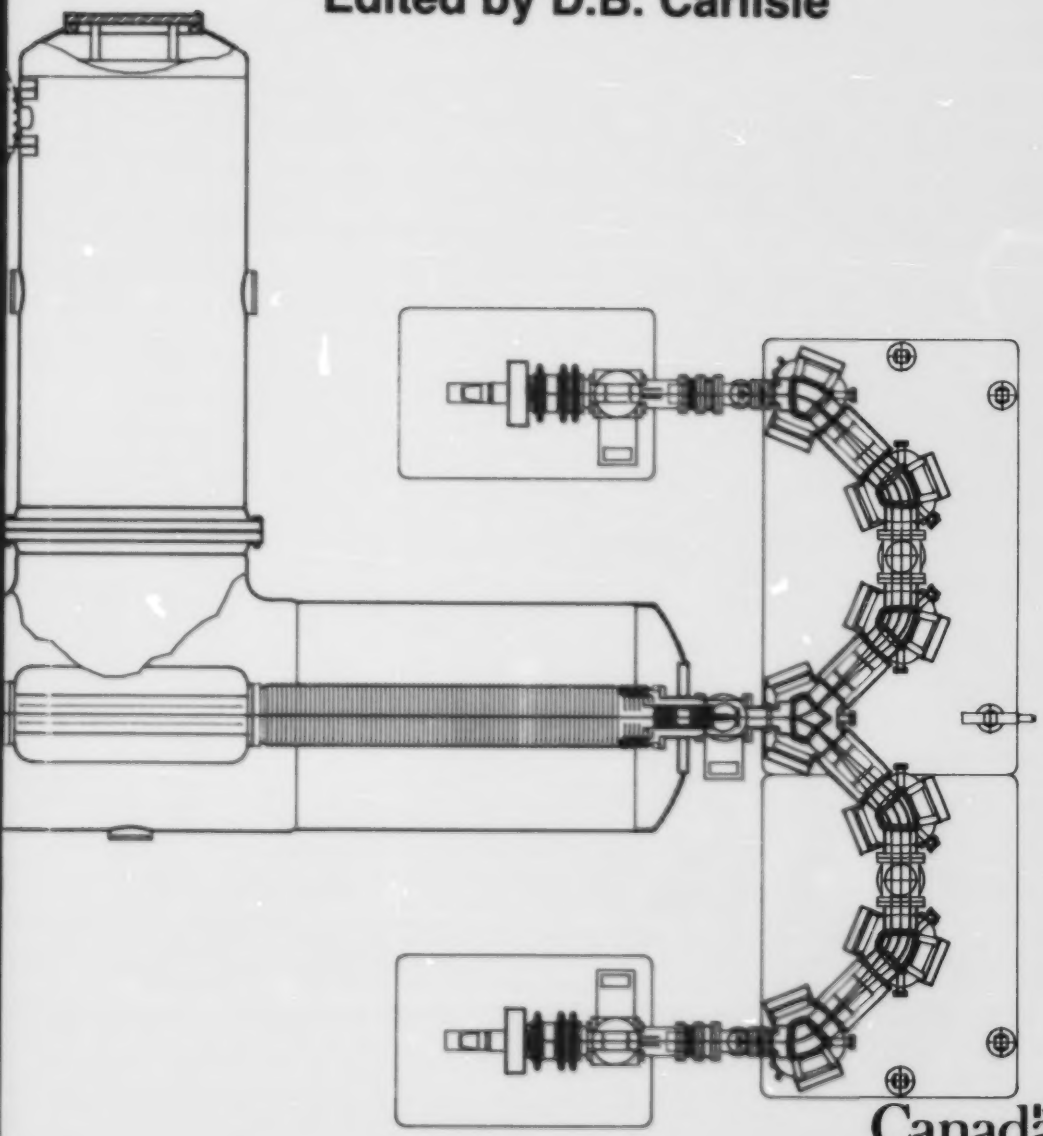
AMS REQUIREMENTS IN CANADA

Edited by D.B. Carlisle



Canada

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The Future of Accelerator Mass Spectrometry in Canada:

Report on a Workshop
held at the

Canada Centre for Inland Waters
Burlington, Ontario, Canada
15-16 April 1991

Edited by

David Brez Carlisle

Environment Canada, Ottawa, Ontario, Canada, K1Y 0H3

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The illustration on the cover is a schematic diagram of the newly installed (but not yet fully operational) AMS machine at the Woods Hole Oceanographic Institute, Massachussetts. The semicircular structures on the front cover were designed in Canada (US patent # 50-13923, held by the University of Toronto).

Editor's Note

As soon as I became aware of the Rochester experiments in 1977, which demonstrated the feasibility of AMS, I realized its potential in the environmental sciences. When a group at the University of Toronto proposed, the next year, to set up an AMS facility I lobbied hard to obtain funds in order to facilitate the growth of the discipline. No other AMS proposal ever crossed my desk until recently. In the event, IsoTrace, at the University of Toronto, was established with funding from four sources, including my own department. Since then I have endeavoured to be a facilitator, not actively engaged in AMS, but trying to improve the conditions for its practice in Canada and attempting to push those aspects which impinged most closely on environmental science. This has led to my being identified with IsoTrace, only because this is currently the one laboratory in Canada which is currently dedicated to AMS.

These efforts have contributed to establishing the policies by which IsoTrace has established its high reputation. It is my hope that not only IsoTrace but Canada in general will, over the next few years, improve this situation and attain a commanding lead in this area of science. It is to this end that this workshop was convened, to define how practitioners and more especially users of AMS felt about the future of the technique and about further developments in its utilization.

I was surprised at the scope of the opinions expressed and the clear need defined for further facilities in the future. In this report I have endeavoured to present the opinions expressed at the workshop, especially the majority opinions, though never neglecting the minority views. While I agree with many of the views expressed, this is not true of all of them. In any case, I am not presenting my own views, but rather my understanding of the views of the workshop. I trust my own perception of what occurred is not too biased by my own convictions.

I have edited individual contributions as little as possible. The reports from individual working groups (section VI) have received greater editing. The general conclusions were written with input from many volunteers at the close of the workshop. I wrote the summary, which has been further discussed and edited by the original organizing committee of the workshop, but all mistakes, omissions and distortions remain my responsibility.

Summary

Only one laboratory in Canada, IsoTrace, is currently dedicated to AMS, but even there some of the equipment is rapidly reaching the end of its useful life and must be upgraded as soon as possible. International participants were anxious to ensure that the commanding lead shown by Canada in certain aspects of AMS should not be further eroded.

The demand for AMS analyses is rapidly growing and will soon exceed capacity (currently about 1,500 analyses per year). Archaeology has historically been perceived to be the greatest user of ^{14}C analysis, but for several years past it has only accounted for about 20%. Projected total demands for the near future suggest a potential need for about 6,000 analyses per year, while five years hence the demand in Canada may exceed 53,000 per year, including 31,000 projected for medical diagnostics and 10,000 for materials science. These needs cannot be met by existing AMS facilities, even if they were to receive adequate funds for maintenance and operation (which they do not at the moment). The projected needs can only be met by additional capacity. High precision ^{14}C demands another machine in the near future. In addition biomedical projections suggest that an additional specialized facility will be needed for this discipline. This year, several hundred medical samples were sent from Canada for analysis elsewhere. A further facility will be needed for work in materials science, heavy elements and economic geology.

Such initiatives can only succeed if there is collaboration between government departments and granting agencies, the universities, private industry and the Provinces.

Any AMS facility will require an on-site preparation laboratory, but it may be advantageous in certain circumstances to establish in addition independent preparation laboratories.

Participants felt that user fees were too high and seemed to be subsidizing research into AMS R&D. If user operating grants cannot be increased to reflect the real costs of analysis then AMS facilities will require greater direct funding. The current demand for analyses (as opposed to the perceived need) is currently limited by inadequate funding.

The shortage of trained personnel will form a bottle-neck and a major training effort should be funded.

No one source of funds will be adequate for the expansion recommended by participants. Considerable additional funding will be needed from NSERC in the first place, both to upgrade existing facilities and for at least one additional machine. Medical Research Council should be chiefly responsible for funding a new facility for biomedical research, while industry may be expected to be the chief (but not the sole) source of funds for a facility for materials science and economic geology.

For the immediate future granting agencies should concentrate on providing funding to upgrade IsoTrace, including the provision of a second machine dedicated to ^{14}C analysis. The restoration of facilities at McMaster University for ^{36}Cl work should also be considered.

Résumé

Il n'y a qu'un laboratoire au Canada, IsoTrace, qui soit consacré à la Spectrométrie de Masse par Accélérateur (AMS). Malheureusement l'équipement est devenu désuet et doit être amélioré ou remplacé aussitôt que possible. Les participants internationaux dans cet atelier furent convaincus que le Canada ne devait pas céder sa position de commande en ce qui concerne certains aspects du travail AMS.

De plus en plus le monde scientifique exige des analyses par AMS et un surcroît rapide du nombre de ces commandes mettra l'efficacité canadienne d'agir en jeu (il y a couramment plus de 1,500 analyses qui se font au Canada par année). Une perception erronée fut que des analyses ^{14}C étaient couramment utilisées autrefois par l'archéologie. En réalité, depuis plusieurs années cette discipline ne rend compte que de 20% des analyses seulement. On estime que les demandes totales atteignerons bientôt 6,000 analyses par an, et en cinq ans pourraient excéder 53,000 analyses par an, si on y inclus 31,000 analyses pour le diagnostique médicale et 10,000 analyses pour les sciences de la matière. Ces besoins ne peuvent pas être satisfaits par nos moyens AMS actuels, même si l'entretien et le fonctionnement étaient subventionner adéquatement (ce qui n'est as le cas présentement). Les besoins anticipés ne seront satisfaits qu'avec une capacité largement augmentée. La grande précision qui est exigée par ^{14}C impose l'aquisition d'une autre machine pour AMS au si tôt que possible. En outre, une deuxième installation specialisée sera requise pour servir la discipline biomédicale selon nos provisions. Déjà cette année plusieurs centaines d'échantillons médicaux ont été envoyés en dehors du Canada pour analyses. En plus, une troisième installation sera nécessaire pour des investigations dans les sciences des matières, des éléments lourds, et de la géologie économique.

Ces initiatives ne peuvent pas réussir s'il n'y a pas une collaboration parmis les départements gouvernementaux, les agences donatrices, les universités, l'industrie privée et les provinces.

Chaque installation AMS a besoin d'un laboratoire sur place pour les préparatifs, mais dans certaines circonstances il serait avantageux d'établir des laboratoires indépendants.

Les participants des séances de travail ont tous constaté que les frais versées pour se servir des laboratoires et leur équipement étaient trop élévés, et

paraissaient même subventionner les recherches en AMS et le développement de l'équipement. Si les allocations pour les usages operationels ne peuvent pas être augmentées au moins jusqu'au niveau des coûts réels des analyses, alors les installations AMS auront besoin d'obtenir des fonds plus directement. Le nombre des analyses qu'on nous demande de faire au Canada couramment (en contraste avec les besoins que nous prevoyons satisfaire) sont à leur limite à défaut de fonds adéquats.

Il y a aussi le manque de personnel entrainé créant une impasse dans le travail AMS. Un effort de formation considérable devra être consolidé bientôt.

Une unique source de fonds ne permettra pas le développement recommandé par les participants de l'atelier. En premier lieu, un niveau de fonds additional devra être octroyé par le CRSNG et augments considérablement par la suite. Cela permettra non seulement l'amélioration des installations existantes mais au moins permettra l'acquisition dune autre machine AMS. La responsabilité du Conseil de recherches médicales est d'allouer les fonds nécessaires d'une nouvelle installation consacré aux recherches médicales, tandis que l'industrie privée pourrait être la source principale (mais non pas la seule) de fonds pour une installation dédiée aux sciences des matières et à la géologie économique.

Dans un futur immediat les agences donatrices devront plutôt subventionner IsoTrace avec les fonds requis pour son eventuelle amélioration. Celles-ci devraient aussi prendre en main les dispositions nécessaires pour l'obtention d'une deuxième machine consacrée aux analyses de ^{14}C. La restauration des installations à l'Université McMaster, consacré aux investigations sur ^{36}Cl, est aussi une priorité.

II. Introduction

Long Term Planning for Accelerator Mass Spectrometry in Canada

There are strong indications that Canada will need some expansion and further development of Accelerator Mass Spectrometry (AMS) facilities in order to meet the expected need over the next decade. In addition to the steadily growing radiocarbon dating requirements of the earth sciences and archaeometry, it is expected that the earth sciences will also require an ever increasing number and variety of analyses of other long-lived radioactive isotopes such as ^{7}Be, ^{10}Be, ^{26}Al, ^{36}Cl and ^{129}I. This is especially true for those sciences seeking to understand global environmental change. There are also indications of an increasing interest in the use of AMS for tracer studies by the life sciences and for the study of rare atomic species by the material sciences and the platinum group elements by the earth sciences.

This workshop was called, under the sponsorship of the Natural Sciences and Engineering Research Council and of Environment Canada, to address the long term planning for AMS in Canada. All Canadians who were known to be interested in the technique, either from the point of view of using a facility or as potential AMS scientists, were invited. In addition, notices were sent to all Canadian universities and science departments. Finally, experts from other countries were invited in order to give us the benefit of their experience.

Background

Accelerator mass spectrometry is a technique used for the analysis of low concentrations of specific rare atoms or isotopes in which conventional mass spectrometry equipment is augmented by the use of a charged particle accelerator. The additional energy imparted to the ions, from the analyzed material, makes possible the break up of interfering molecular ions and the counting and potentially background-free identification of the ions of interest on a single ion basis. In a number of important cases, such as ^{14}C and ^{14}N, the use of negative ions results in the complete separation of these isobars. AMS is capable of routinely analyzing concentrations at a level of one part in 10^{12} level for most materials and in specific cases at one part in 10^{15}.

In 1977 Canadians played an important role in establishing AMS as a new analytical tool. A group from the University of Toronto carried out their initial work at Rochester in the United States, which later resulted in the establishment of the IsoTrace laboratory in Toronto, dedicated solely to AMS. Concurrently, a group from Simon Fraser and McMaster Universities developed an AMS capability at McMaster over a number of years. Some AMS measurements have also been carried out using the MP tandem accelerator at the Chalk River Nuclear Laboratories of Atomic Energy of Canada Limited.

There are now at least seven dedicated accelerator mass spectrometers in use around the world. In addition, a number of other accelerators have had mass spectrometers of various kinds added to them for specific purposes. Several new facilities are under construction or active development, notably, one at the Woods Hole Oceanographic Institute, (WHOI), in Massachusetts, one at the Lawrence Livermore Laboratory in California and another at North Texas State University. The laboratory at the Centre National de Recherche Scientifique, at Gif-sûr-Yvette in France is currently upgrading its mass spectrometer and a number of other laboratories are at various stages of planning or development, including ones at Purdue University in Indiana, at Groeningen in Holland, at Nagoya in Japan and at Edmonton, Alberta.

Five years ago, long term planning for AMS in the United States was in a chaotic state, with various universities and research institutes moving without any kind of coordination to prepare individual plans for installing AMS equipment. At that time, NSF called a nation-wide workshop (to which IsoTrace, McMaster/Simon Fraser and Chalk River personnel were invited) to develop a long term plan for AMS in the United States. This resulted in a valuable planning document, which is now being used. More recently, on November 3rd 1988, a report by an AMS Advisory Committee in the USA on Geoscience Research with AMS was released.

The topic of the future of accelerator mass spectrometry was also included in the program of the International Symposium on Advanced Nuclear Energy Research held in Japan on January 24-26, 1990. The Japanese are currently seeking the funding to install the third generation of AMS equipment.

The situation in Canada today is similar to the chaotic state seen in the United States five years ago, and in some ways it is worse, since the current and projected demand for AMS is now greater. Accordingly we organized this workshop whose objective was to develop a long term plan for AMS in Canada. This reports presents the results of our deliberations.

The Current Status of AMS in Canada

IsoTrace is the only full-time dedicated AMS facility operating in Canada at present. Supported from its inception in 1978 by NSERC, Energy, Mines and Resources and Environment Canada, it is one of the few instruments which was not dedicated solely to making measurements. The IsoTrace Board of Directors (on which both supporting government departments are represented) has always determined that some of the available time on the machine and of the total facility should be devoted to research and development in AMS as well. As a result, IsoTrace can analyze radiocarbon samples which are older than those which can be analyzed by the other machines and produces results whose precision is three to five times better than can be obtained from the other instruments. In addition, as a result of extensive research, IsoTrace is pioneering the use of AMS for heavy elements and has developed analytical capability for ^{129}I, the analysis of which has previously required much larger accelerators. As a consequence IsoTrace is at the forefront in aspects of the technology and has been asked by other laboratories, notably those at Gif-sûr-Yvette and Woods Hole (through the US-AMS Corporation), to provide or assist in the design of equipment and software.

One option for the IsoTrace laboratory would be to acquire a second accelerator mass spectrometer which would be dedicated mainly to radiocarbon analysis, freeing the original machine for other analytical work and research. This second machine would be able to provide the most precise radiocarbon measurements possible and to extend the time range of such measurements. This, however, was only one of the options explored at the workshop.

The equipment developed by the Simon Fraser group for radiocarbon analysis at McMaster has now been transferred to the Lawrence Livermore Laboratory in California. McMaster has in the past expressed an interest in continuing some AMS work especially with the isotope ^{36}Cl (important for groundwater research), which requires the larger accelerators used in the past mainly for nuclear physics. To establish an AMS program there will require further planning.

Chalk River is using a large accelerator and they too have begun ^{36}Cl studies, but here it is not clear how the AMS work will interact with the important nuclear physics programs on the superconducting cyclotron. In principle the complete Chalk River accelerator system could also study some of the rare heavy elements which are accessible only to the highest energy machines.

Planning for future facilities in Canada is perhaps furthest advanced in Alberta, where a consortium of the Alberta Research Council, the University of Alberta and several Provincial

Government Departments are currently producing a business plan for the financing of an AMS laboratory. They have held a public planning meeting, and have had some input from IsoTrace.

Institut Lamontaigne and Institut Armand Frappier in Québec have both expressed interest in developing AMS, and planning is going forward at the former. A group at the Université du Québec à Montréal is planning to establish a sample preparation laboratory in order to send initially CO_2 and, later, machine-ready samples to IsoTrace. Funding for a similar laboratory has been requested to prepare oceanographical samples for ^{14}C dating and environmental samples for ^{129}I analysis at University of British Columbia and TRIUMF.

With the Simon Fraser equipment now out of the country, the current capacity in Canada for AMS measurements of all kinds is approximately 1500 analyses per year, of which no more than 600 could be for ^{14}C.

Current Users of AMS Technology in Canada

The statistics in this section have been obtained largely from the IsoTrace user list and the reports of the Simon Fraser Group in the McMaster Tandem Laboratory Annual Report for the last two years during which they worked there. There may be other AMS users who send samples to other laboratories, so these numbers are essentially minima.

At present the largest group of users in Canada consists of geologists and other earth scientists, who employ ^{14}C analyses for studies including sea-level and isostatic rebound in the Arctic, sedimentation rates in lakes and coastal regions, climate change and the incursion of the sea associated with the last deglaciation, groundwater distribution and pollution, meteorite terrestrial life times, and the sources of atmospheric aerosols and greenhouse gases. At least 100 scientists fall within this group.

Another important use of AMS in Canada is in archaeology, where AMS is a preferred method of ^{14}C dating for a variety of samples. Archaeological demand in Canada has so far been met by IsoTrace and by McMaster/Simon Fraser, with some analyses also going abroad. Total analyses for this purpose alone have recently amounted to about 200 per year and have been increasing steadily. A limiting factor to the growth appears to be the money available for analyses, and if the archaeologists receive larger grants then this would be immediately reflected in the additional requests for more and improved analyses. Archaeologists using AMS for ^{14}C dating in Canada number at least 30 drawn from all provinces, as well as from the Territories.

Environmental uses being actively developed include the dating of

groundwater, the mobilization of aluminum in medical problems and its role in the acidification of lakes, and ^{129}I as a marker of radioactive plumes (e.g. those from nuclear waste storage sites and nuclear weapons material production reactors. Approximately a dozen Canadian scientists are involved in these studies at the moment.

Miscellaneous users include museums, which, in addition to using AMS extensively in the above mentioned fields, occasionally use this technique in the authentication of artifacts and art objects.

Future uses include oil well logging, the monitoring of isotopes of importance to Global Change studies, but perhaps the most immediate future large scale use is in connection with the World Ocean Circulation Experiment, where ^{14}C studies of deep oceanic waters will play a major role. In the US portion of this collaborative effort NOAA has called for the analysis of enough samples from the oceans to occupy all the existing AMS facilities (world-wide) for five years. Moreover, the specifications they have published could at the moment be met only by IsoTrace and possibly Zurich since high precision is required. Accordingly, new facilities are needed, and the facility at WHOI currently being built (with the help of some Canadian technology) is the first step in this program. The requirements for the Canadian share of the Experiment are not yet finalized, but we may expect that they, as well as the requirements for other studies connected with Global Chance will undoubtedly add further load to the present facilities. Biomedical science and materials science are also potential heavy users of AMS in the near future.

Finally, from the experience gained at the IsoTrace laboratory, it is clear that there is need for an active program of pure research and development in AMS itself in order to keep pace with and contribute to the advancement of this technology throughout the world and to meet the new demands brought by the users. Such a program also provides an excellent training ground for the new personnel which will be needed to staff the facilities required in the twenty-first century.

All indications suggest that Canada will need some expansion in AMS facilities to meet the expected need over the next decade. The extent of this potential expansion was determined during this workshop and long-term planning initiated because of the long lead time needed to develop existing or create new facilities with trained staff.

Structure of the Workshop

Sponsors:

National Science and Engineering Research Council.
Environment Canada.

Convenors:

D.B. Carlisle, Research Scientist, Environment Canada, Ottawa.
A.E. Litherland, Director, IsoTrace Laboratory, University of Toronto.

Organizing Committee:

D.B. Carlisle
W.E. Kieser
A.E. Litherland
I.V. Mitchell
J.C. Rucklidge
S.D. Scott
T.C. Young

All known Canadian users and identifiable potential users of AMS were invited, together with experts from other countries. Some 80 attended. In addition, written submissions were requested from anyone who was unable to attend. So far as possible these were circulated before the workshop and are reproduced here.

The workshop proceedings lasted two days. The program will be found in appendix A. The first morning was devoted to and overview of AMS capacity around the world, with papers by non-Canadian experts. The first part of the afternoon saw a brief review of Canadian capabilities and potentials, after which the participants divided up into seven working groups, according their particular interests:

Earth Sciences
Chair: H. Schwarz (McMaster University)

Oceanography and marine geology
Chair: G. Vilks (Atlantic Geoscience Centre)

Archaeology
Chair: P. Julig (Laurentian University)

Biomedical Science
Chair: D. Milton (Chalk River Laboratories)

Hydrology and Limnology
Chair: R. Andrews (Chalk River Laboratories)

Materials characterization
Chair: J. Brown (University of Western Ontario)

Trace elements in economic geology and geochemistry
Chair: G. Wilson (Turnstone Geological Services).

Foreign visitors and convenors made themselves available during this period to any of the working groups who desired assistance of any kind.

During the evening the international (non-Canadian) participants met as an eighth working group to offer their recommendations.

On the second day the reports of these eight working groups were presented by their chairmen to a plenary session, and provoked lively discussion. These reports form section VI of this report.

Finally, the general recommendations from the plenary session were written up that evening, on the basis of notes presented by the working group chairmen. This task was undertaken by a group of volunteers (all participants were asked if they wished to volunteer) under the chairmanship of D.B. Carlisle; IsoTrace staff were excluded from this chore, since it was felt that they might be biassed. This set of general recommendations forms part VIII of this report.

Acknowledgements

The organizing committee owes a special debt of gratitude to the non-Canadian participants, who gave us the benefit of their advice and assistance:

M. Anthony	USA
J. Barker	UK
P. Damon	USA
D. Elmore	USA
W. Mook	Netherlands
H. Polach	Australia
K. Purser	USA
J. Sisterton	USA
J.S. Vogel	USA

Alice Leung, who carried the burden of the secretarial services for this workshop, and B.K. Afghan, who made the local arrangements, both gave invaluable help. Notable help was received from Bonnie Blackwell, Jim Brown and A.R. Mermut. R.C. Carlisle wrote the French résumé. Staff and students of IsoTrace all assisted in the smooth running of the event; in addition to those mentioned above they include:

R. Beukens, R. Cresswell, L. Kilius, M.-J. Nadeau and Zhao Xiao-Lei.

III. AMS Capacities Worldwide

AMS Facilities in the USA: Present Capabilities and Near-term Plans

David Elmore

PRIME Lab
Physics Building
Purdue University
West Lafayette, IN 47907-1396

Introduction

The United States has played a leading role in accelerator mass spectrometry (AMS) since 1977 when Muller suggested using accelerators to measure long-lived radionuclides [1] and the first radiocarbon measurements were performed at the University of Rochester in collaboration with the University of Toronto [2,3] and at McMaster University [4]. The first detection and much of the development work for the radionuclides ^{26}Al, ^{36}Cl, ^{41}Ca, and ^{129}I took place in the United States. Although ^{10}Be was first measured with a cyclotron in France, the methods presently used with a tandem accelerator were developed in the U.S.

At this time there are nine accelerator laboratories active in AMS in the USA (Table 1). This review covers the current capabilities (based on recent performance) and plans for the near future at these laboratories. My information comes from articles in the Proceedings of the Fifth International Conference on AMS published in *Nucl. Inst. Meth.* Vol. B52, 1990 (papers with U.S. authors are listed at the end of this report), from results of a mail survey of the AMS laboratories, and from personal communications. As a result, this is an informed but personal view of AMS research and policies in the USA. I am responsible for any errors.

Additional material is available to the interested reader. A review of AMS published in *Science* covers both the technical and scientific research aspects of AMS and includes many references to publications by U.S. authors [5]. Copies of "The future of accelerator mass spectrometry in the USA, proceedings of an interagency briefing and workshop to explore the needs and opportunities for AMS applications", D. Elmore, ed. (Washington, D.C. March 28-29, 1985) are available from PRIME Lab. Finally, an NRC report "Facilities for Earth Materials Research" addresses the present status and needs for AMS along with three other classes of Earth Science instrumentation. It contains, as an appendix, the report of the (U.S.)Accelerator Mass Spectrometry

Advisory Committee: D. Elmore (ch), R. Finkel, G. Jones, J. Klein, T-L. Ku, D. Lal, A. Long, F. Phillips, J. Sarmiento, K. Turekian, and M. Wahlen. Copies of this report are available from U.S. Geodynamics Committee, National Research Council, 2101 Constitution Ave. N.W., Washington, D.C. 20418.

Table 1. AMS laboratories in the USA.

All labs have tandem electrostatic accelerators and, in addition, Argonne has an electron cyclotron resonance (ECR) ion source injecting into a superconducting linac. The labs at North Texas, Purdue, and Woods Hole are in a start-up phase. The approximate fraction of beamtime for AMS is given for accelerators shared with other (nuclear physics) uses. Radionuclides are listed in order of decreasing number of samples measured per year. Accelerators were manufactured by General Ionex Corporation (GIC), High Voltage Engineering Corporation (HVEC), National Electrostatics Corporation (NEC), and US-AMS Corporation. GIC, US-AMS, and HVEC no longer manufacture accelerators.

AMS Lab	Accelerator	Status	Nuclides
Arizona	GIC 2.5 MV	Dedicated	^{14}C, ^{10}Be
Argonne	ECR + Linac	Shared 5%	development of ^{39}Ar, ^{81}Kr, ^{85}Kr
Livermore	HVEC FN 8.5 MV		Shared 25% ^{14}C, ^{10}Be, ^{36}Cl, ^{26}Al, ^{3}H; future: ^{41}Ca, ^{129}I
North Texas	NEC 3 MV	Shared 50%	trace impurities
Pennsylvania	HVEC FN 10 MV		Shared 25% ^{10}Be, ^{26}Al, ^{41}Ca, ^{36}Cl, ^{14}C, ^{3}H
Purdue	HVEC FN 8 MV		Dedicated ^{36}Cl, ^{10}Be; future: ^{26}Al, ^{41}Ca, ^{14}C, ^{129}I
Rochester	HVEC MP 15 MV		Shared 25% ^{36}Cl, ^{129}I, trace impurities
Washington	HVEC FN 9 MV		Shared 10% ^{14}C
Woods Hole	US-AMS 2.5 MV		Dedicated ^{14}C

A short description of the current status and plans for each of the nine U.S. laboratories is given in Tables 1 and 2. Additional information specific to each laboratory can be found in publications listed at the end. I have not given credit to the many individuals responsible for development and measurements at each lab. Many of these people are authors of publications in conference proceedings; I have also given addresses and phone numbers for contact persons at each laboratory.

When reporting numbers of samples measured at each lab, I will always report the number of unknowns. There are typically another 20-30% more samples measured that consist of standards, blanks, and repeat samples. The radionuclides routinely measured by AMS are ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca, and ^{129}I; these are referred to here as "AMS radionuclides".

AMS laboratories operating prior to 1985

At the time of the AMS workshop in Washington, D.C. (March 1985) there were four AMS labs in the USA that were measuring over 100 samples per year. These labs are at the universities of Rochester, Washington, Pennsylvania, and Arizona. Rochester, Pennsylvania, and Washington have large (7-15 MV) tandem accelerators funded primarily for studies in basic nuclear physics and shared by AMS activities but without corresponding support from the Earth sciences. The University of Arizona has a small (2.5 MV) accelerator dedicated to AMS and supported by the National Science Foundation (NSF) Geosciences Directorate.

In 1977 several physicists at the University of Rochester began a major program to develop AMS techniques and this lab became the first to measure several of the AMS radionuclides. All six AMS radionuclides were measured at Rochester. Although considerable effort was given to radiocarbon in the early years, the precision and cost were not competitive once dedicated ^{14}C labs at Arizona and Toronto became operational. Partly because of early collaborations with hydrologists, the Rochester program concentrated on the radionuclides ^{36}Cl and ^{129}I. Recently this group developed a neutron activation/AMS technique for measuring depth profiles of nitrogen and chlorine in pure materials. Development of a gas-filled magnet is in progress. Currently the AMS program uses 25% of the accelerator time (1300 hours in 1990). Capacity is several hundred samples per year. Isotope switching and data reduction have been automated; final results are typically available one week after samples are measured. Precision ranges from 3 to 10% depending on sample size and isotope ratio. Major research areas include surface exposure dating of glacial moraines, ground water tracing, and meteorite studies. About 25% of the scientific research is

Table 2. Research areas for AMS laboratories that measured at least 100 radionuclide samples (unknowns) in 1990.

	Arizona	Livermore	Pennsylvania	Rochester	Washington
Agronomy	C				
Archaeology	A	B			
Art work	A				
Atmospheric chem	B			B	B
Biomedical		A	B	C	
Dendrochronology	A				
Earth Sciences	A	B	A		B
Environment		A		C	B
Geomorphology	B		A	A	
Hydrology	B			A	
Polar science	A		B		
Materials				C	
Meteorites	A		A	A	
Oceanography	A	B			B
AMS development	B	A	B	B	B

Key: A, over 50 samples; B, 21-50 samples; C, 1-20 samples.

Note that some samples could be listed in more than one research area so that the absence of a letter does not necessarily imply no activity in that area.

based at Rochester, the remainder involves collaborations with outside (mostly U.S.) scientists.

The University of Washington AMS program began in 1977 and presently uses 5-10% of the accelerator time for radiocarbon measurements. They measure about 100 samples per year and report 0.5% precision on samples of 200-400 microgram carbon. Most scientific research is based internally and subject areas encompass Earth, ocean and atmospheric sciences.

The University of Pennsylvania AMS program began in 1979 and has made major development contributions to measurement of ^{10}Be, ^{26}Al, and ^{41}Ca. Particularly noteworthy are advances in ion sources that have enabled excellent sensitivity for these hard-to-produce negative ions. They developed a continuous normalization system for ^{10}Be that eliminates the need for cycling magnets and provides excellent throughput and precision. In the past year they have measured about 700 ^{10}Be samples, 250 ^{26}Al samples, and 70 ^{41}Ca samples. They have recently demonstrated AMS of ^{36}Cl with a high-intensity ion source and measured 30 ^{36}Cl samples in 1991. Major research areas include exposure ages of Antarctic rocks and meteorite studies. Research projects at Pennsylvania have a strong internal component and they do not accept service work.

The long-term future for the AMS efforts at the universities of Rochester, Pennsylvania, and Washington is uncertain. The Nuclear Physics Divisions of the funding agencies have become increasingly reluctant to fund applications in the Earth sciences at these labs. The physics faculty members directing the AMS programs at Rochester and Pennsylvania labs are not too far from retirement; of the three physics faculty at Washington, one (Fred Schmidt) died recently and one other has already retired but continues to perform AMS measurements. At all three universities the physics departments have been unwilling to hire replacement AMS physicists at the tenure-track faculty level. It is unlikely that the AMS programs would survive long without participation by nuclear physicists.

In 1980, the University of Arizona received funding from the National Science Foundation for a regional dedicated radiocarbon laboratory. They obtained first results in 1982 and are now measuring 1700 radiocarbon samples per year. The current backlog is 600 samples. They routinely achieve 0.6% precision for 500 microgram samples of modern carbon. Scientific research areas cover a broad spectrum (see Table 2); in 1990 highest on the list were oceanography (460 samples), Earth sciences (385), archaeology (190), art works (160), and polar sciences (120). About 25% of the measurements were for scientific programs based at Arizona. In 1990 they spent six weeks on ^{10}Be development and measured 20 ^{10}Be samples.

Laboratories started after the 1985 workshop

Although the effects were not immediate, the 1985 workshop in Washington marked a turning point for AMS in the USA. At that time the three shared AMS facilities and one dedicated radiocarbon facility were not able to handle the demand from the geoscience community. Sample backlogs were high (over 1000 samples at times) and turn-around times were long (6-9 months for some nuclides). Independently, funding initiatives were directed towards the NSF Ocean Sciences, NSF Earth Sciences, and the Department of Energy. Eventually, new facilities were founded at Woods Hole Oceanographic Institution, Purdue University, and Lawrence Livermore National Laboratory.

The National Ocean Sciences AMS Facility at Woods Hole Oceanographic Institution was funded by the NSF in January 1989. The 3 MV accelerator system built by US-AMS Corporation was delivered in the fall of 1990. Accelerator time is expected to be divided as follows: 70% for global programs such as WOCE and GOFS, 20% for marine geology, and 10% for other radiocarbon applications. Their goal is to measure 3000-4000 samples per year at 0.3 to 0.5% precision. Everything from sample preparation to data analysis will be fully automated.

Purdue University dedicated its model FN (8 MV) tandem to AMS and provided initial funding for construction of an AMS injector and AMS beamline in 1989. The Purdue Rare Isotope Measurement Laboratory (PRIME Lab) recently obtained first results for ^{36}Cl and ^{10}Be. Their goal is to become a national facility capable of measuring the full range of AMS radionuclides; however, the present funding level from NSF Earth Sciences Division limits their capability to a few hundred samples per year (primarily ^{10}Be, ^{36}Cl and ^{26}Al) for internal and a limited number of collaborative projects.

Lawrence Livermore National Laboratory built a new multipurpose accelerator laboratory centred on an FN tandem obtained from the University of Washington in 1985. With funding from the Department of Energy and the University of California they installed, starting in 1987, a large AMS spectrometer. The Center for AMS (CAMS) presently utilizes 25% of the accelerator time but this may grow to 50%. CAMS has measured 1500 radiocarbon samples since March 1989 and report typical accuracy of 1-1.5%. CAMS is also measuring ^{3}H, ^{10}Be, ^{26}Al, and ^{36}Cl. The internal and collaborative scientific research program includes biomedical dosimetry, pharmacokinetics, the carbon cycle, and geophysical isotopic records.

Specialty AMS laboratories

There are two U.S. laboratories that are active in AMS but do not have plans to measure AMS radionuclides for a substantial number of samples: Argonne National Laboratory and the University of North Texas.

Argonne National Laboratory has a superconducting linac (effective acceleration voltage 40 MV) with two injector systems supported by the Department of Energy primarily for basic studies in nuclear physics. The FN tandem injector, used in conjunction with the linac for AMS since 1979, is presently being phased out. The Argonne AMS group made many important scientific measurements with this system including half-lives, nuclear cross sections, ^{41}Ca in bones, and development of the gas-filled magnet for isobar separation. The new positive-ion injector consists of an electron cyclotron resonance (ECR) ion source and a low-beta superconducting linac section. The AMS group is presently developing the ECR plus linac for detection of ^{39}Ar, ^{81}Kr, and ^{85}Kr. This has many advantages for AMS including efficient production of high intensity positive ions from any element, destruction of molecules, high stability, self regulation, and high abundance selectivity. However, much development work is needed to eliminate memory effects and to separate isobars.

The University of North Texas in collaboration with Texas Instruments Corporation has constructed an AMS system for detection of (stable atomic) impurities in electronic materials and metals. Based on a NEC 3 MV tandem, the layout is similar to other AMS systems with two major differences. (1) The sputter ion source contains a caesium mass analysis stage to remove impurities that originate in the caesium and the caesium extraction electrodes. This, together with an ultra-high vacuum in the sample region, is needed to reduce contamination of the element of interest to below the 10^{-12} level. (2) Because isotopic abundances are not as low as natural levels of AMS radionuclides, fewer mass analysis stages are used. Additional magnets would probably be needed for detection of the AMS radionuclides at natural levels. The accelerator is used about half time for atomic physics and ion beam analysis (channelling, PIXE, NRA, and RBS).

AMS Laboratories no longer active

There are several accelerator laboratories that have performed some AMS analyses in the past but are not, to my knowledge, active at the present time. These include the Lawrence Berkeley Lab, Navai Research Laboratory, Rutgers, Minnesota, Los Alamos, Yale, and Brookhaven. The Naval Research Lab

measured tritium with a cyclotron. Rutgers University measured ^{10}Be but have recently sold their FN tandem to the Australia Nuclear Science and Technology Organization (ANSTO), Lucas Heights, Australia.

The AMS user community in the USA

In the description of the AMS laboratories above I have made some distinction between internal research and collaborations with research based at other institutions. Overall probably no more than 20-30% of the research is internal. Coverage of all user groups is beyond the scope of this paper; information on these can be obtained from the AMS conference proceedings. Participation by these outside users is essential for the continued operation of the AMS laboratories in the USA.

Chemical sample preparation usually comprises 30-50% of the total cost of each analysis and, except for the radiocarbon labs, much of this work is carried out by outside collaborators.

Three user groups that have been particularly important to the functioning of the U.S. AMS laboratories are located at the University of California at San Diego, New Mexico Institute of Mining and Technology, and the Department of Terrestrial Magnetism, Carnegie Institute of Washington.

Conclusions, recommendations, and the future

The nine AMS labs in the United States cover a broad range of radionuclides, research areas, geographic locations, and sources of funding. Although there is never enough funding and the total capacity is always too low, the most optimistic view for the near future places the U.S. in a position comparable to other countries when adjusted for national research effort. On the other hand, a pessimistic view (i.e. shutdown of the shared facilities at Pennsylvania and Rochester and no increase in funding for Purdue and Livermore) would place the U.S. well below present capabilities in Canada, Switzerland, and Australia when adjusted for national research effort.

The analytical needs for a particular radionuclide can change faster than the AMS labs in any one country can adjust. Therefore it is important that countries share their AMS capacity. Currently, for example, many U.S. radiocarbon samples have been measured at Toronto and Zurich, and Rochester has measured Canadian and French ^{36}Cl samples. AMS laboratories are run most efficiently at high capacity, therefore it may not be wise for a country to build a new facility if it needs only half of one.

If a country needs only a few hundred samples per year for some radionuclide, it may be best to make arrangements with a neighbouring country, perhaps in trade for analyses of a different radionuclide.

Performance for a particular radionuclide depends on the size of accelerator. A tandem in the range 2-3 MV has been shown to be adequate for ^{14}C, ^{26}Al, and ^{129}I although the accelerator efficiency can be somewhat greater for these radionuclides at 6 MV. For ^{129}I, and to a lesser extent for ^{26}Al, three large analysis magnets and two electrostatic analyzers are required. The magnets are usually available on larger accelerators and contribute substantially to the cost of AMS systems on small tandems. ^{10}Be has been measured below 3 MV at Arizona and at Gif-sur-Yvette. The efficiency of these systems is well below that possible at higher energies; precision for low-level ^{10}Be analyses is considerably better at Pennsylvania. With present technology, ^{36}Cl requires at least 6-8 MV accelerators.

New tandems above 3 MV are not readily available and are prohibitively expensive. However, a number of HVEC tandems are available from nuclear physics laboratories that are no longer funded. The cost of upgrading these and building automated AMS systems is comparable to new 3 MV systems but with the advantage of being able to measure all AMS radionuclides. Zurich has shown that a larger tandem can be made to produce high precision ^{14}C analyses (0.2%). Once in operation the larger AMS system costs somewhat more to maintain.

Is there enough AMS capacity in the USA? Clearly not if one takes the pessimistic view mentioned above. Even if one takes the optimistic view of funding and survival of the shared university labs, there may be a shortage, especially for radiocarbon analyses. Of the new AMS labs, Woods Hole will be booked to near capacity with large oceanography projects. Livermore is a shared facility and is allocating much of its AMS time to biomedical projects. Purdue effort, so far, is directed towards the non-^{14}C radionuclides. Thus, although overall capacity has increased greatly in recent years, the amount of machine time available for radiocarbon analyses in archaeology and earth sciences has not increased substantially. The situation is aggravated by the possible shut down of several radiocarbon decay-counting labs.

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Contact Persons for AMS Laboratories in the USA

Dr Mark Anthony
Texas Instruments Inc.
P.O. Box 225936
MS 147 Dallas, TX 75265
214-995-3981 Fax:214-995-5539

Dr. Jay C Davis
Center for AMS
Lawrence Livermore National Lab.
Livermore, CA 94550
415-423-1414 Fax:415-423-7884

Professor Douglas J. Donahue
Department of Physics
University of Arizona
Tucson, AZ 85721
602-621-2480,-6825 Fax:602-6214721

Professor Jerome L. Duggan
Physics Department
University of North Texas
P.O. Box 5368
Denton, TX 76203-5368
817-565-3252, -3250 Fax:817-565-2599

Professor David Elmore
PRIME Lab
Department of Physics
Purdue University
West Lafayette, IN 47907-1396
317-494-6516 Fax: 317-494-0706

Professor George W. Farwell
Nuclear Physics Lab, GL10
University of Washington
Seattle, WA 98195
206-543-6327 Fax: 206-543-9285

Professor Udo Fehn
Department of Geological Sciences
University of Rochester Rochester, NY 14627
716-275-7884

Professor Harry E. Gove
Nuclear Structure Research Lab.
University of Rochester
Rochester, NY 14627
716-2754943 Fax:716-473-5384

Dr. Pieter M. Grootes
Nuclear Physics Lab GL10
University of Washington
Seattle, WA 98195
206-543-6327

Dr. Glenn A Jones
Woods Hole Oceanographic Inst
Woods Hole, MA 02543
508-457-2OOOx2585 Fax: 508-457-2183

Dr. A.J. Timothy Jull
Department of Physics, Bldg 81
University of Arizona
Tucson, AZ 85721
602-621-6816 Fax: 602-621-4721

Jeffrey Klein
Department of Physics
University of Pennsylvania
Philadelphia, PA 19104
215-898-5962,-8832 Fax:215-898-2010

Dr. Walter Kutschera
Physics Division, Bldg 203
Argonne National Laboratory
9700 South Cass Avenue Argonne,IL 60439
708-972-4026

Professor Roy Middleton
Tandem Accelerator Laboratory
Department of Physics
Philadelphia, PA 19104-3859
215-898-3658,-8832 Fax:215-898-2010

Dr. Roben J Schneider
Woods Hole Oceanographic Inst. Woods Hole,
MA 02543 508-457-2OOOx2756

U.S. Authors contributing to AMS-5

The proceedings of the 5th International Conference on Accelerator Mass Spectrometry were published recently in Nuclear Instruments and Methods Vol B52, Nos. 3 and 4 (1990). The following papers had at least one United States author and so represent U.S. contributions to AMS.

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22) **I.D. Proctor, J.R. Southon, M.L. Roberts, J.C. Davis, D.W. Heikkinen, T.L. Moore, J.L. Garibaldi, T.A. Zimmerman.** The LLNL ion source-past, present, and future. pp. 334-337.

23) **K.H. Purser, A.E. Litherland.** The elimination of charge-changing backgrounds in an AMS radiocarbon system. pp. 424-427.

24) **K.H. Purser, T.H. Smick, R.K. Purser.** A precision ^{14}C accelerator mass spectrometer. pp. 263-268.

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26) **F.H. Schmidt, T.A. Brown, G.W. Farwell, P.M. Grootes.** The University of Washington AMS system: a six-year technical update. pp. 229-232.

27) **P. Sharma, P.W. Kubik, U. Fehn, H.E. Gove, K. Nishiizumi, D. Elmore.** Development of ^{36}Cl standards for AMS. pp. 410-415.

28) **J.R. Southon, M.W. Caffee, J.C. Davis, T.L. Moore, I.D. Proctor, B. Schumacher, J.S. Vogel.** The new LLNL AMS spectrometer. pp. 301-305.

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AMS Facilities in Europe

W. G. Mook

Netherlands Institute for Marine Research
Texel, The Netherlands

In this brief report I present a review concerning the status of operation of the European AMS-systems. I will restrict myself to those which, to my knowledge, provide results for external projects on a routine basis, or will do so in the near future. A listing of facilities will be found overleaf.

General remarks:

1. The North American continent needs more AMS capacity for ^{14}C with at least 0.5% precision (many oceanic and atmospheric samples from North America are analyzed in Zurich and New Zealand; 500 samples per year at IsoTrace is too small a number for potential Canadian needs).

2. A new AMS facility should be dedicated to ^{14}C (this is a necessity for obtaining the best precision and the highest efficiency).

3. The ^{14}C dedicated AMS facility should be unique in Canada (all ^{14}C samples should be submitted to this one facility).

4. The new AMS facility (dedicated to ^{14}C) should ideally have full responsibility for all stages of analysis, from original sample judgment to ^{14}C measurement (no peripheral chemical treatment, combustion and target production). However, it is the opinion of several of my colleagues that peripheral ^{14}C laboratories could keep in contact with sample submitters, judge and treat the samples to prepare CO_2, which can then be sent to the AMS facility in break-seal glass ampoules as is done at present.

5. The new ^{14}C AMS facility should make full use of the existing expertise in Canada (with respect to ^{14}C dating; of course there are advantages in using the Toronto infrastructure completely).

6. It is essential that the turnaround time in the AMS facility be as short as possible. As short a time as two weeks would be ideal for many samples.

Table of European Facilities

Location	AMS	Main Isotope	Approx. No. of Analyses per Year	Field
Uppsala	Part-time (EN)	^{14}C	1000	Various
	Under discussion: a central facility in Scandinavia for 4000 ^{14}C samples per year (HVEE Tandetron?).			
Zurich	Full-time (EN)	^{14}C (37%)	1300	Various
		^{10}Be (14%)	850	Ice/Oceans etc
		^{26}Al	300	
		^{36}Cl	250	
	30% of ^{14}C analyses as service (Switzerland, Germany, USA); technical improvement planned for higher through-put.			
Gif-sur-Yvette	Full-time (Tandetron)	^{14}C	300	Various
		^{10}Be		Ice/Oceans
	Higher through-put of ^{14}C required (an additional 200); interested in ^{14}C dedicated machine.			
Oxford	Full-time (Tandetron)	^{14}C	600	Archaeology
	Some effort devoted to CO_2 ion-source research			
Utrecht	Part-time (EN)	^{14}C	600	Earth
		^{10}Be		Sciences
Groningen	Full-time (HVEE Tandetron, Amersfoort; planned)	^{14}C	(1500)	Various
	AMS system under construction; will be installed by the end of 1991			

In addition to the active or funded facilities given above a proposal for an additional facility has been prepared and the order awaits financial approval:

Kiel	Full-time	^{14}C	?	Oceans

A Review of Accelerator Mass Spectrometry In Australia and New Zealand

Henry A Polach

Director, Research Consultations
PO Box 43, Garran ACT, Australia 2605
(formerly Head, ANU Radiocarbon Dating Research Unit Canberra)

Introduction

What follows is a personal view of the Australian and New Zealand AMS endeavours in terms of current or proposed facilities, achievements, motivating forces and political/financial factors in relation mainly to radiocarbon dating. Technical details are not given as these, in view of the second hand equipment used as a basis of both the New Zealand and Australian AMS facilities, are not pertinent to the aims of the Workshop. The sources of material were Annual Reports and research publications from the four Institutions that play a major role in Australia and New Zealand as well as personal contacts with research leaders of the named institutions.

In Australia:

The Australian National University (ANU), Research School of Physical Sciences and Engineering (RSPSE), Canberra ACT, (^{10}Be, ^{14}C, ^{36}Cl and ^{129}I)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Mineral Physics, North Ryde NSW, (PIXE, RBS, NRA, ^{10}Be and ^{14}C)

The Australian Nuclear Sciences and Technology Organisation (ANSTO), Applications of Nuclear Physics Division, Lucas Heights NSW, (^{10}Be, ^{14}C)

In New Zealand:

Department of Scientific and Industrial Research (DSIR). Physical Sciences, Nuclear Sciences Group, Lower Hutt, (^{14}C).

Activities in New Zealand

The former Institute of Nuclear Sciences, DSIR, now incorporated in a larger Division of Physical Sciences, played, from the very beginning a major role in the development of ^{14}C dating, first by radiometry, with gas proportional counting experiments as early as 1949 and now by AMS. The first AMS samples were run in November 1986. Thus the New Zealanders have become very early significant players in the ^{14}C international field and have retained this position due to the excellent support they lend to world wide Quaternary, archaeological and environmental research and due to critically selected self-generated research in distribution of ^{14}C in the oceans and atmosphere of the Southern Hemisphere.

The basis of their AMS success is a re-worked and much improved upon EN Van de Graaf tandem accelerator, purchased second hand from ANU, Research School of Physical Sciences in 1985.

In the first full year of operations, July 1987 to June 1988, some 280 ^{14}C determinations with a precision of 2-3 % were made. One third of these were system checks and calibrations, one third atmospheric methane and sea water carbon dioxide and the rest projects relating to Quaternary, archaeological and geochemical studies originating in New Zealand, Australia and USA.

In the year 1989/90, the last period for which an Annual Report is available, 1,000 determinations were carried out to equal to or better than 1% precision. 470 of these were calibrations and standards, 180 were internal projects relating to atmosphere and ocean and 350 were commercial dates mainly from USA and Australia.

Generally the vast majority of samples are less than 3,000 years old and the current limit of 40,000 years is not detrimental although it does affect the accuracy of the few samples that are older than 20,000 years. The increase in commercial activities is due to the New Zealanders actively advertising in geological and archaeological international journals, keeping the prices attractive (slightly less than is normally charged in the USA) and promising and achieving a turnover of eight weeks between receiving a sample and reporting of results.

To sustain such an effort a computer data base has been set up that enables the recording of the movements of a sample throughout the dating process; from the

time it is received, pretreated, converted into a target, AMS determination, age calculation and consultation with and reporting of results to the submitter. The data base also virtually automates the generation of age reports and of accounts in the case of commercial samples.

Some commercial activities were always part of the New Zealand scene. However, the current user-pay policies forced, in the last 2 years, an increase of commercial activities. These activities are no longer limited to outsiders but the user-pay policies, so I understand, apply even to interdepartmental activities within the DSIR. If there is a limiting factor to overall productivity then this is seen in the sample pretreatment and purification prior to its conversion to a target rather than in age determination by AMS; possibly also in the time taken in consultation with commercial users, some of whom inevitably embrace dating techniques for the first time, and in the time taken to seek, follow up and keep tabs of commercial activities and budget balancing acts.

On the other hand, the New Zealanders report that increasingly batches of samples (10-30) are received from the same submitter. The AMS daters question if this is due to their bulk discount policy which may indeed encourage a "measure it and see" approach rather than the hitherto step by step evaluation of a small number of dates.

Funding of research activities, not seen to be returning an immediate income or a wider commercial benefit to the nation, has always been available in New Zealand, although in a very limited way. It is thanks to the personal achievements of leaders in ^{14}C research like Athol Rafter, Gordon Fergusson, Bernie O'Brien and now Rodger Sparks (AMS at DSIR) and Alan Hogg (Radiometry at the University of Waikato) that New Zealand today is regarded as making a significant international contributions to widely applied radiocarbon dating research. Their frequent ability to 'do it alone' and 'build it themselves' as well as their selection of research topics of international interest will continue to guarantee their success.

New Zealand radiocarbon dating demonstrates:

> Parallel collaborative developments in radiometry by liquid scintillation spectrometry and AMS.
>
> An increase in productivity in both radiometry and AMS. The increases in activities are ^{14}C research demand-driven and motivated.
>
> The ability to survive in an atmosphere of diminishing recurrent funding and severe international competition.

I value their contributions as being nationally and internationally very significant and is so recognised by their peers.

Activities in Australia

The Australian continent is very rich in natural archives recording all Quaternary events and hence, not surprisingly, Australian researchers are very active and successful in the fields of geochronology and Quaternary, archaeological and environmental research. It is thus somewhat surprising that radiocarbon dating by radiometry commenced seriously only with the establishment of a Radiocarbon Unit at ANU as late as 1965 and that to date there is no dedicated AMS facility in Australia producing routinely a large number of age determinations, There certainly is no lack of research projects that would benefit from ^{14}C dating by AMS and no lack of demand for ^{14}C dates. Based on this demand a number of quite complex initiatives have been taken as follows:

The Australian National University (ANU) through its Research Schools of Pacific Studies (RSPacS) and Earth Sciences (RSES) supports a well established and productive radiometric ^{14}C facility that served as a model for the establishment of similar facilities at the University of Sydney, the CSIRO Division of Soils, Adelaide, and the ANSTO Nuclear Applications Section at Lucas Heights. All are very productive and will serve as centres of input for ^{14}C dating by AMS by drawing in samples from their 'Quaternary Network' (incorporating virtually all Australian Universities and Research Organisations and Institutions), purifying and pretreating these samples to isolate the carbon fraction to be dated and preparing targets to a unified procedure yet to be established by the ANU Radiocarbon Unit.

The current AMS status is as follows:

1. The Research School of Physical Sciences and Engineering at ANU (RSPSE) operates a 14UD high energy accelerator that is used principally for basic nuclear physics research but has also proven ideal for ^{36}Cl measurements. These have utilised about 15% of available accelerator time over the past four years. Some AMS research effort has also been devoted to the detection of ^{10}Be and ^{14}C. The difficulties, originality and success of detection of, for example ^{36}Cl, in absolute rather than relative terms, demonstrates that there always was and will continue to be a need for AMS fundamental research as opposed to routine dating of a large number of samples. It is the view of the ANU physicists that their aim will be to continue their support of AMS based research and the development of AMS technology in order to serve selected collaborative projects and post graduate education needs. Service determinations and commercial activities to meet *ad hoc* demands are not their aims.

The RSPSE successfully detected ^{36}Cl as early as 1985 and contributed to collaborative research with the Australian Nuclear Sciences and Technology

Organization (ANSTO) (formerly the Australian Atomic Energy Commission), the Bureau of Mineral Resources (BMR) and CSIRO by producing several hundred ^{36}Cl determinations yearly, related to hydrological and terrestrial sediments chronological studies.

These activities were assisted by the appointment of an ANSTO Post Doctoral Fellow located during 1987 to 1989 at RSPSE. Since his departure ANSTO have continued to support the ^{36}Cl program albeit at a substantially reduced level. Chlorine-36 measurements (recurrent and capital expenditures and technical staff support) are funded from ANU/CSIRO, State Water Research, BMR and other organisations research grants, mostly on a collaborative project basis and sometimes on a per sample basis. The most significant features are that:

^{36}Cl can be detected in absolute terms and not relative to a standard;

^{36}Cl sample reduction chemistry and target preparations must be carried out in a calm environment away from nuclear reactor sites. Such 'clean rooms' have now been constructed at the RSES; and

computer control of measurement sequences has been implemented to enhance the routine and precision of ^{36}Cl determinations.

Radiocarbon dating at RSPSE did not fare quite as well mainly because the demands were not coordinated, major projects were not identified and hence not funded, and research activities were based on *ad hoc* collaborations between the ANU radiometric daters and 14UD physicists. Nevertheless proof of ability to detect ^{14}C became available during 1988 though characterised by poor graphitic target ion beam reproducibility and poor beam transmissions resulting in results within 10% of radiometrically predetermined values. The first of these problems has been resolved and during 1989 a significant number of ^{14}C determinations were carried out with a precision of 3-5%. Funding for a completely new injection system, to solve the problem of poor beam transmission, was received during 1990. However, the key researcher spent all of 1990 overseas and the ^{14}C AMS project was thus in abeyance during that year. However, upon his return early in 1991 and the start of the installation of the new injection system, it is expected that a much enhanced ^{14}C capability will be attained by mid 1991.

The Radiocarbon Dating Unit (RSPacS) has acquired, during 1990, dedicated pretreatment rooms suitable for the handling, in a clean environment, of milligram size samples and has built experimental lines to test bulk target production techniques and is collaborating with RSPSE, ANSTO, New Zealand, Livermore, Tucson and Woods Hole AMS researchers on these matters.

The foreshadowed increase in AMS dating activities during 1991 and onward

by ANU nuclear physicists, will be based on collaborative projects of significance to Quaternary and environmental researchers. These dating activities are seen as essential to maintain the interest of Australian geochronologists and demonstrate to them and the funding agencies the potential of AMS. The ANU ^{14}C AMS activities will also serve to bridge the gap before the planned dedicated AMS facility at ANSTO comes on line. Then the AMS facility at the RSPSE will continue to serve selected research topics and as the Australian post graduate research training and teaching AMS centre.

The other ANU RSPSE activity relates to the development of ^{10}Be spectrometry. I understand that the ^{10}Be project is collaborative with ANSTO and that BeO sample preparations will be undertaken at the Lucas Heights ANSTO Laboratories.

2. **The Division of Mineral Physics CSIRO**, North Ryde, commenced operations of their Heavy Ion Analytical Facility (HIAF), based on a 2.25 MV Tandetron (General Ionex Corp, USA) mid 1983. Their main objective was to set up facilities for accelerator based analytical techniques such as Particle Induced X-ray Excitation (PIXE) for material studies and detection of trace elements in minerals; Rutherford Back Scattering (RBS) for chemical and structural analyses; Nuclear Reaction Analysis (NRA) for depths profiling of elements and hydration studies; and Ultra Sensitive Mass Spectrometry (USMS). The HIAF facility generates and sustains collaborative research with other Divisions of the CSIRO and Universities predominantly in the field of minerals and energy related industry.

The USMS ability of the Tandetron to detect ^{10}Be and ^{14}C for geochronological studies, and the demand for these facilities in the Australian research context, made it logical for the Division of Mineral Physics to be involved in all discussions and plans mooted by ANU, CSIRO or ANSTO for the establishment of a dedicated AMS facility to Quaternary and environmental studies. Indeed, I understand that in a successful pilot study a limited number of ^{14}C standard and blank determinations were carried out mid 1990, a year in which also a collaborative ANU/CSIRO ^{14}C research program relating to further target testing had commenced. Further developments along these lines are the planned collaborations with ANSTO and ANU in testing graphitic targets for ion beam characteristics. It is envisaged that research at HIAF can materially assist the establishment of dedicated AMS at ANSTO. The opportunities and need by CSIRO to engage in routine ^{10}Be and ^{14}C are also being investigated. The facilities and willingness are certainly there but the funding for staff and equipment necessary to produce beryllium and radiocarbon determinations routinely in significant numbers does not seem to be forthcoming.

3. The most significant and in my view the only Australian initiative that will lead to the establishment of a National

AMS Facility was taken by the **Applications of Nuclear Physics Division of the Australian Nuclear Science and Technology Organisation (ANSTO)**, Lucas Heights, NSW. ANSTO has, upon receiving a 'one-off' establishment grant from the Federal Government, purchased a second hand FN Tandem from Rutgers University, USA, and set it up, totally re-worked and refurbished, in AMS dedicated premises at Lucas Heights. From totally internal resources a staff of eight professional physicists and a number of technical staff have dedicated their efforts over the last two years and on schedule tested the Tandem before the end of 1990. This augurs well for the promised first ^{14}C experimental results mid 1991 and commencement of prudent routine ^{14}C dating early in 1992.

The stated intentions are to dedicate 80% of AMS time to radiocarbon dating, in the first three years of routine operations, drawing upon input of prepared targets from the already established radiometric ^{14}C dating laboratories (ANU, CSIRO, University of Sydney and ANSTO). The identified driving sciences range from archaeology to ocean sediments with considerable emphasis on atmosphere (greenhouse effect), and high resolution chronology of climatic and hydrologic changes in the last 1000 years, etc. As is customary in Australia, the sampling and fieldwork is undertaken by a network of loosely associated but uncoordinated researchers from all Universities, Institutions and Government Departments that have an interest in chronological studies. This wide research base is an excellent source of multidisciplinary and interdisciplinary activities, with many perspectives and points of view being represented and pursued. However, it is a very poor source for financing research requiring major capital investment. This may be the reason why ^{14}C by AMS in Australia has so far suffered.

The Federal Government, in a bold move to bolster research and industry interaction, announced that it will fund Collaborative Research Centres (CRC) and asked for bids for these before the end of 1990, A consortium involving in the first instance eight Universities, three major research organisations, two major Industries and a number of Government Departments in NSW and the ACT, proposed to form a CRC for the Application of Accelerator Mass Spectrometry'. This demonstrates the wide interest in, and demonstrated achievements and value of, geochronological research in Australia. Notwithstanding, it is my understanding that the Federal Government has not put the AMS CRC proposal on a high priority list to be acted upon in 1991. Therefore, it will remain the full responsibility of ANSTO to pursue the AMS establishment policies as best as they can from rather restricted recurrent budgetary allocations. Financial assistance from other Universities or research organisations is unlikely but some research support will be forthcoming from ANU and CSIRO.

It is the expressed desire of the ANSTO

AMS group not to let the lack of further financial support affect their time table. However, it is almost certain that their scope, and productivity will, at least in the short term of the next few years, be affected and significantly reduced.

Comments and Recommendations

As far as Funding Organisations are concerned, Accelerator Mass Spectrometry is big science, therefore the criteria used to judge proposals for the establishment of AMS Centres anywhere in the world are never entirely scientific; regional, national and international considerations (rivalries, prestige, politics) are also involved. As a result AMS Centres which serve major driving sciences such as oceanography stand a better chance of being funded than those who 'dissipate' their research energy and potential in a broad spectrum of significant yet individually minor interdisciplinary consultations. On the basis of their science these, lesser projects nevertheless are valuable and the AMS Centres that serve them perform a unique and difficult 'value added service'.

One feature common to all major projects (big science) appears to be the oversell by scientist and politicians of the research merit of mega projects and the underestimation of their cost, technical difficulties and time factors, and the overestimation of productivity, precision, quality and significance of the results. Ongoing funding provisions (recurrent costs) seem to suffer in all cases where grant dependent Centres were established, be they small or big. Much of the Dating Centre's energy is spent on making fund generating proposals, monitoring income and chasing creditors.

In the ^{14}C dating world applied to Quaternary and environmental sciences it can be argued that it paid so far to 'think small'. Many major goals were achieved (such as calibration of the time scale, past sea level or climatic changes, etc) by a number of modest laboratories with relatively modest equipment at relatively modest costs. These projects were based on the needs of the driving sciences rather than the desire to come up with or use new technology.

Nevertheless there are areas where 'thinking big' is either highly desirable or is clearly the only means of achieving a specified result. While scientific considerations should take precedence it is inevitable that political considerations will influence the project and that desirable national or international collaborations may not be feasible.

Thus uncertainties that can be perceived as being part of the scientific project should be incorporated in the process of evaluation of merit of any new AMS facility. Because we prefer to look at scientific matters as generating certainties rather than doubt we do not make

provisions for sharing the risk of the project when the project takes longer to give desired results or the blame when the project goes wrong.

I presume that the Canadian scene is not different from those I see in Holland, Australia, New Zealand and USA, for example. I note that all existing AMS Centres are being hampered by lack of recurrent operational funds. This makes it difficult to maintain a driving edge by attracting top rate talent and the question needs to be asked if newly proposed Centres will fare any better in the future, or if existing Centres are expected to continue to struggle or fall by the wayside?

If nothing else, then the technical options and the research projects will need to be defined, productivity and cost assessed in realistic terms and provisions for ongoing support made when seeking to establish a new AMS facility.

It is my view that any new AMS facility ought to:

Have a mandate for the development of AMS on a national basis with a mission of substantial collaboration with other Universities and Institutions in the nation.

Play an important role as a major centre of research in areas of national importance, research education and training at the highest international level and to be a resource of highest achievable AMS output at lowest cost.

Establish a bridge between national and international research communities thus strengthening the nation's capacity to undertake fundamental research as well as research related to the nation's needs.

Have as its continuing mission to gain research visibility and international respect and become more of a national resource for other Universities and Institutions.

Have a mandate to conduct research with the necessary autonomy and intellectual independence with provision for appropriate policy advice.

Have its recurrent funding separately identified and provided for on a long term and *increasing* (not diminishing) basis whilst being encouraged to tap other and various sources of funding so that different areas of inquiries are not neglected.

Be run by a Director of high academic standing to further strategic planning and strengthen the coherence of research. His brief should include involvement in major budgetary issues and the Chairmanship of a Consultative Committee to be set up to assist him in establishing research priorities and strategies. The Consultative Committee should be appointed by the funding body and be advisory to the Director and should have a broad national base of external members with an international flavour

if appropriate.

The Consultative Committee should:

Define the program of interactions with other Universities and Institutions and establish Visiting Fellowships for staff and Visiting Postgraduate Programs for students.

Define the levels of costs associated with the programs and the total operating budget available to the AMS Centre. Take into account that when interactive programs are put into operation and productivity increases so will the total costs, whilst the cost per sample will be reduced.

Establish an Interim Advisory Committee to broaden the pool from which ideas are drawn, advise on various research programs and their costing and the appropriate minimum level of activities that will ensure validity and progress and enhance national and international collaboration.

Define programs of regional, national and international significance and evaluate their impact on collaborations with other Institutions as well as cost of implementing these projects and collaborations.

As to 'user-pay policies' it is my observation that, whenever these apply, administrative tasks increase at the expense of scientific and technical endeavours. The philosophy that money rather than knowledge is the driving force behind science is generally alien to researchers. Certainly, researchers seldom have any training or experience in 'money management'; mostly such activities are forced upon them. I cannot endorse user pay policies as being pertinent or attractive to any National AMS facility.

Acknowledgements:

R Sparks (DSIR), K Fifield (ANU), S Sie (CSIRO) and J Boldeman (ANSTO) have made written submissions and commented critically upon this report. I thank them for their efforts. Nevertheless, this report represents a personal and not an official view of AMS related research and policies in Australia and New Zealand.

Accelerator Mass Spectrometry Facilities in Japan[1]

Yasunori Miura

Yamaguchi University, Yamaguchi 753 Japan

Of the twelve principal accelerator laboratories in Japan, four are currently used, at varying levels, for accelerator mass spectrometry. Details of these facilities are summarized in table 1.

The only dedicated AMS facility in Japan is located at Nagoya University. This provides ^{14}C analysis primarily for the earth sciences. Samples are analyzed for studies in climate change, atmospheric chemistry, fossil dating, earthquake dating, ocean circulation, groundwater hydrology and archaeology.

One field which requires more AMS analyses is the study of extra-terrestrial material (e.g. meteorites, lunar samples and cosmic dust). The Japanese Polar Institute (NIPR) holds the world's largest collection of Antarctic meteorites (> 10,000) and measurements of their terrestrial, glacial, buried and surface ages are required. Additional analysis is required for meteorites of lunar and Martian origin and primordial meteorites.

There are plans to install one more dedicated AMS facility and to add the capability to several other existing accelerators. However, under the current economic conditions, these plans are currently being held in abeyance.

[1] This paper was not presented orally at the workshop but was circulated in manuscript form.

Table 1: Principal AMS Facilities in Japan

AMS Lab	Accelerator	Status	Nuclides
Kyoto	NEC 8UDH	shared 5 %	^{10}Be, ^{14}C, ^{26}Al
Nagoya	GIC 3MV (4130A)	dedicated	^{14}C
Osaka	AV Cyclotron	shared 5%	^{41}Ca
Tokyo	4MV TD	shared 25%	^{10}Be, ^{14}C, ^{26}Al

Status of tandem based Accelerator Mass Spectrometry Facilities in China

Li Kun & Chen Chia-Erh

Department of Technical Physics
Peking University, Beijing 100871, China

Introduction

Four Institutes in China plan to develop their own facilities. They are:

Institute of Atomic Energy (CIAE), using an HI-13 tandem based system;

Institute of Heavy Ion Physics, Peking University, with an EN tandem and fast switching injection system;

Institute of Modern Physics, Lanzhou (IMP), with a 2 MV vertical tandem; and

Shanghai Institute of Nuclear Research (SINR), with a 6 MV vertical tandem and a mini-cyclotron based system.

We shall introduce in the general features of tandem-based AMS facilities being developed in China and their applications.

General Features of AMS Facilities in China

HI-13 tandem based system at CIAE

The HI-13 is specially designed by HVEC for the purpose of general heavy ion studies. To some extent it also suits the requirement of an AMS system. So far no special efforts or modifications have been made other than setting up a dedicated beam line after the HE switching magnet along a deflecting angle of 15°.

To eliminate the isotopic and isobaric backgrounds the beam line is equipped with a high resolution 15° electrostatic deflector (R = 360 cm) and a 3-plate E-ΔE ionization chamber which is set 2 m down from the magnet for the final identification of the wanted nuclide. In addition, a Canberra S-88 analyzer and VAX 11/780 computer are used for data acquisition.

The first test of ^{36}Cl was carried out with two standard samples having $^{36}Cl/^{35}Cl$ ratios of 1.69×10^{-9} and 1.65×10^{-11}. The Cl current was typically 3-6 μA and the overall transmission of $^{35}Cl^{9+}$ at 8 MV was 3%.

EN tandem AMS Facility at Peking University

The Oxford EN tandem contributed greatly to development of AMS technique, but after its re-installation at Peking University a new dedicated AMS system was designed and constructed for the analysis of Be, C, Al, Cl and nuclides.

A number of efforts have been made to eliminate the fractionation effect so as to improve measurement accuracy. A fast switching sequential injection system, for instance, is installed to enable the isotopes of interest, e.g ^{12}C, ^{13}C and ^{14}C, to go along the same axis from the source up to the analyzing magnet via the accelerating tube. All lenses, including the quadrupoles, and steerers used in this section will be fully electrostatic rather than magnetic. In addition, all apertures of the beam elements are wide enough for transmission to be essentially independent of mass to the 90° analyzing magnet. Under control of a timer the duration of transmission of the most abundant isotopes will be set at 0.3 ms and 1 ms respectively for ^{12}C and ^{13}C for example, so that the beam loading effect is minimized.

To remove the isotopic and isobaric backgrounds the whole system includes three bending magnets (90°, 90° and 45°) with mass resolution of 160, 1,000 and 200 and a 20° cylindrical high resolution electrostatic deflector, combined with a E-ΔE counter telescope as the final particle discriminator. Typical analyzed beam current of $^{12}C^{3+}$ is 0.5 μA and for $^{19}F^{4+}$ 0.3 μA.

The data acquisition system is based on an IBM PC/XT computer with interface software which allows display, analysis and manipulation.

Shanghai Institute for Nuclear Research

A vertical 6 MV tandetron tandem accelerator was designed, constructed and installed for general studies in Nuclear Physics and applications. In order to fulfil the requirements of AMS applications, modifications have been made to the ion source, beam optical system and other related elements.

An improved version of the ion source with a target wheel of 18 sample positions was developed, based on the

structure of the Hiconex 860. 350 μA C^-, 10 μA of BeO^- and 5 μA of Al^- ions have been obtained. Low memory effect was also proven by the fact that ion yield attenuation was greater than 1,000-fold within less than 30 minutes.

The beam emerging from the tandem is analyzed first by a cross field velocity selector together with a 90° analyzing magnet and then, after passing through a switching magnet, by a 10° electrostatic deflector. The analyzing system permits suppression of the neighbouring isotopes by a factor of 10^{13}.*IMP*

The 2 MV tandem at IMP was the first China-made tandem in operation. A dedicated AMS beam line with an electrostatic deflector, a gas-filled magnet and an E-ΔE detector is planned and will set up after the 90° analyzing magnet.

Applications

Preliminary applications have been planned by all four institutes constructing AMS facilities.

CIAE tends to put more effort into heavier nuclides. They will be engaged in studies such as

- the repositories of nuclear waste by detecting long-lived isotopes;
- ^{36}Cl and ^{129}I in uranium ore deposits and ground water as a natural analogue system;
- ^{36}Cl in dating salt lakes and meteorites;
- studies of growth rates of manganese nodules.

Peking University will at first be engaged in ^{14}C dating of Malain loess to obtain information on long term variations of the ancient climate, the palaeo-environment and soil erosion processes in loess areas, ^{14}C dating of *Homo sapiens* fossils found in China and ^{14}C dating of Chinese oracle bones. The possibility of ^{10}Be dating for deep sea sediment samples is also included.

Study of ^{10}Be dating or tracer for Jilin meteorites, ocean sediment of the South China Sea, and of manganese nodules are planned at SINR, while IMP will work with ^{14} dating of glacier ice, polar ice and of the weathering layer of the moraine surface.

Table of AMS Facilities under development in China

Institute	CIAE	PKU	IMP	SINR
Ion Source				
Type	834	860[1]	860	860[1]
Sample Holders	12	18	1	18
Injection System				
Pre-acceleration (kV)	80	60	-	60
Magnet (M/ΔM)	90	160	200	106
Altern. Injection	-	10 Hz	-	-
Tandem Accelerator				
High Voltage (MV)	13	6.5	2	6
Stability (kV)	3	3	3	
HE Analyzing system				
Magnet (M/ΔM)	≥2,000	1,000	500	2,000
Electrostatic Deflector	15°	20°	23°	10°

1. Improved GIC 860 type source.

IV. New Areas of Specialization in AMS

Accelerator Mass Spectrometry For Materials Science Applications

J.M. Anthony

Texas Instruments
Dallas, Tx 75265 USA

AMS and Materials

The study of materials and material properties has become an increasingly important field both scientifically and technologically in recent years. The electrical and optical properties of materials are crucial to many defense and private sector projects. A recent study for the United States (US) Dept. of Defense (DOD) has identified 20 "critical technology" areas of strategic importance for future defense systems[1], and at least seven of these technologies (semiconductor materials and microelectronic circuits, photonics, composite materials, passive sensors, biotechnology materials and processes, high energy density materials and superconductivity) depend on materials related developments for their success. At the same time the world market for non-defense electronics and electro-optics is increasing at a dramatic pace. In the electronics industry this has resulted in a phenomenal growth rate for speed and capacity, with an increase in memory capacity (DRAM) of a factor of 10 every 6 - 8 years. Efforts to sustain such a growth rate, coupled with the general importance of materials in both the defense and commercial industries obviously leads to large research budgets for the development of these materials.

Figure 1 shows recent US government expenditures on materials research and development [2] and compares this with a more conventional source of funding for AMS, US government spending for research in the environmental sciences (atmospheric, oceanographic and geological)[3]. The trends are similar, with materials spending about 70% of the environmental total. When the US industrial spending for materials science (about 4x the government support) is included, it becomes clear that there is a

tremendous opportunity for new analytical methods such as AMS which can impact materials related problems.

Basic questions for all these materials include:

What are the properties (electrical, chemical and structural) of the bulk materials utilized? - and:

What happens to these properties during extremes of pressure, temperature, miniaturization etc?

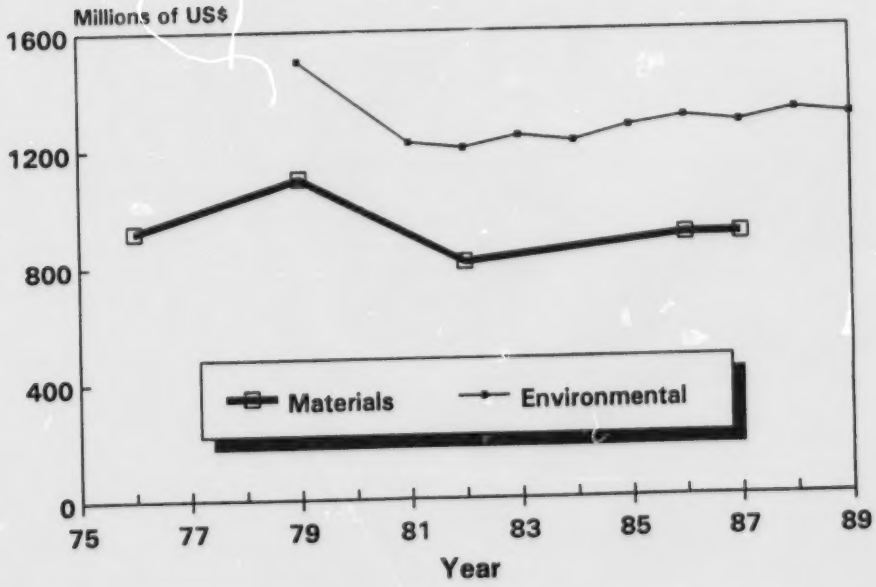


Figure 1. *Total US government expenditure (constant 1982 US dollars) for materials and environmental (atmospheric, geological and oceanographic) sciences. Note - US industry funding for materials is about four times government amount.*

In addition, the interactions of various materials with one another are critical for many applications.

The science of mass spectrometry is most directly applicable to understanding the chemical properties of the materials, ranging from the major components to trace impurities. In many cases the presence (or absence) of trace impurities is crucial for correct material performance. In Si solar cells a study of trace metals[4] has shown that the presence of impurity concentrations at 1 part-per-billion (ppb) atomic can decrease device performance by a factor of 2. At the same time, the presence of dopant atoms (B, P) in the ppb range is required for correct operation. In memory chips, the presence of U and Th in metal layers or packaging materials at trace levels (ppb) can induce soft errors due to alpha particle decay and subsequent charge collection in the memory arrays[5]. Other electronic and optical materials for infrared sensing (HgCdTe, CdTe, CdZnTe), high speed devices and laser diodes for optical communication (GaAs, AlGaAs, InGaAsP, InGaAlP) are all adversely affected by the presence of trace impurities at low levels (ppb and below).

The most common method for high sensitivity, multi-element detection in solid materials is mass spectrometry. (Other techniques, such as neutron activation analysis or photoluminescence, have high sensitivity but limited applicability). In many cases the impurities of interest are masked due to the presence of molecular interferences at the same mass from the matrix atoms or various residual gas atoms. High mass resolution systems can remove these interferences in many cases with a corresponding loss in transmission and increase in system cost. The importance of these problems and the commitment to solving them is demonstrated in Figure 2, which shows the US installations of the most common SIMS (Secondary Ion Mass Spectrometry) system (vendor Cameca Instruments[6]), which couples high mass resolution with high lateral resolution (about 1 μm). These instruments,
which cost about $1,000,000 US, are most common in materials related industries, especially electronic materials.

It is clear that a need exists for high sensitivity analysis of stable impurities in materials. A comparison of AMS with the conventional systems raises several issues:

The ability of SIMS instruments to analyze both positive and negative ions provides increased flexibility and higher ionization efficiency in some cases. Detection of elements with low electron affinities using AMS currently requires the injection of molecular ions.

The yield of the AMS system is primarily determined by the (negative) ionization efficiency and -transmission losses in the stripper (3-5x for full molecular

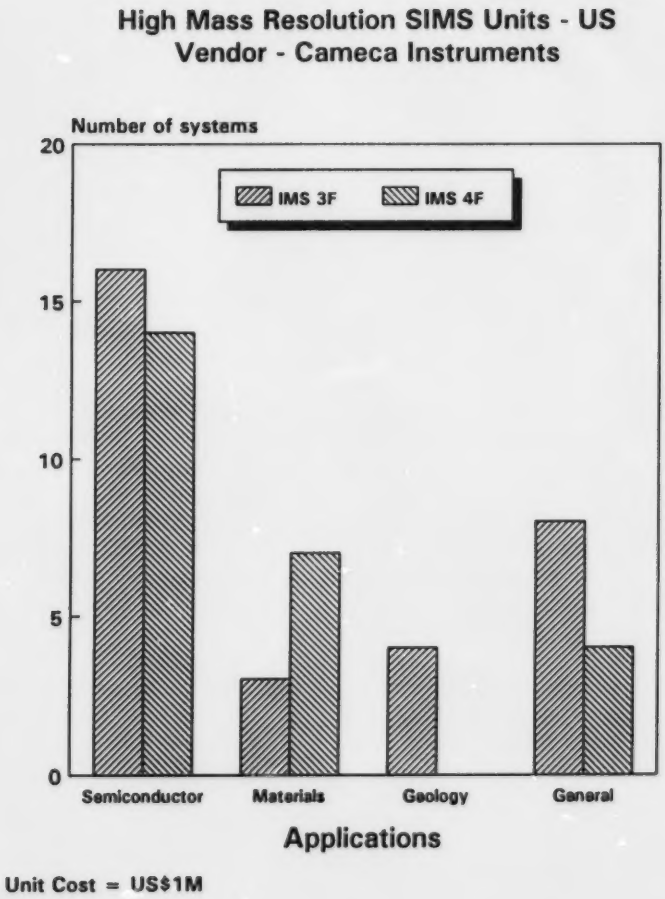


Figure 2. *Number of US high mass resolution SIMS systems (from the most common vendor - Cameca Instruments) as a function of application. Unit cost for these instruments is about US$1,000,000.*

rejection). SIMS yields are determined by the (positive or negative) ionization efficiency and by transmission losses in the high mass resolution mode. The IMS-4f is reported to lose a factor of 5x at a mass resolution of 4500, 10x at 7000 and 30x at 10,000[7] (resolution defined as mass divided by full width at 1/10 maximum), and this resolution is limited to fairly small regions of the sample (about 100 μm).

Maximum lateral resolution is defined by the sputtering beam probe size for both methods. (The Cameca SIMS can operate in an ion microscope mode, but with poorer resolution than the microprobe mode).

Analysis of insulating samples requires charge compensation during sputtering. This is available on SIMS instruments for positive and negative ion extraction, but has not been implemented with AMS.

"Noise" rates in AMS can be near zero due to full removal of interferences and energy spectroscopy at the detector. SIMS is plagued by rates > 0.1 Hz due to scattered particles and dark current on low energy (keV) detectors.

The bulk sensitivity of AMS will be better than SIMS in essentially all cases, but SIMS may provide lower detection limits in low mass resolution applications with limited amounts of material (selected regions on a semiconductor device) due to higher ionization rates. The requirements for an AMS system devoted to stable element analysis are somewhat different from a radioisotope instrument:

Since all elements (except In) have at least one isotope with no stable isobars, the sophisticated detection schemes for separating isobars of different elements are not necessary and can be replaced in most cases by a surface barrier detector coupled with magnetic and electrostatic analysis.

Conversely, many of the impurities of interest are common in ion source hardware and represent a source of sample contamination. This necessitates a redesign of some aspects of the source hardware.

Since high energies for isobar rejection are not required, low terminal voltages (about 1MV) are sufficient for most applications, although this does complicate particle detection somewhat due to large pulse height defects in surface barrier detectors at these low energies.

Current Programs

Several groups have explored or are participating in applications of AMS to stable elements. On-going projects exist at the University of Toronto[8] (ppb level detection of platinum group elements and heavy metals in minerals), the University of Rochester[9] (depth profiling of N, Cl in Si using neutron activation/AMS, platinum group elements in photographic materials) and the University of North Texas[10,11] (electronic materials, metals). A program to couple a Cameca SIMS system to a tandem (1.7 MV) was initiated several years ago in a joint project between Charles Evans and Associates (analytical lab in California with extensive SIMS experience) and the US government, but the project has been on hold for some time due to budget constraints. Other laboratories which have performed experiments or expressed interest include the University of Arizona, IBM and the University of Minnesota.

University of North Texas/Texas Instruments

The University of North Texas (UNT) and Texas Instruments (TI) are constructing an AMS system devoted to the detection of stable element impurities in solid materials. The system is based on a 3 MV NEC (National Electrostatics Corp.) tandem accelerator in the Ion Beam Modification and Analysis Laboratory at UNT. Magnetic (40 degrees, 69 MeV-amu) and electrostatic (45 degrees, 4.8 MeV protons) analysis followed by Faraday cup or surface barrier detection has been implemented on the system, and this hardware has been automated to allow fully computer controlled mass scans. Two conventional NEC ion sources (Cs sputter source, alpha source) are available, and the extracted beam (60-70 kev) is magnetically mass analyzed (90 degrees, about 14 MeV-amu) before injection into the accelerator. Figure 3 demonstrates the operation of the hardware. A sample of bulk Si mounted in the NEC sputter source was mass analyzed (terminal voltage 1.5 MV, charge state 3+), and this result is compared with a similar mass scan of Si performed using a SIMS system (Cameca IMS-3f) . The sensitivity for masses such as ^{31}P, ^{56}Fe, ^{58}Ni, ^{72}Ge and ^{75}As is dramatically enhanced using AMS by removal of the interferences $^{30}Si^{1}H$, $^{28}Si_2$, $^{28}Si^{30}Si$, $^{28}Si_2{}^{16}0$ and $^{29}Si^{30}Si^{16}O$. Elements with zero electron affinities, such as Mn or Zn, are not detected in the AMS scan, as expected, but can be measured through injection of silicide (MSi-) molecules and detection of the fragments. Current detection limits in Si (ppb range for most elements) are defined by contamination from the NEC sputter source.

Figure 4 shows an analysis of steel (stainless #304)[12]. Once again there is no

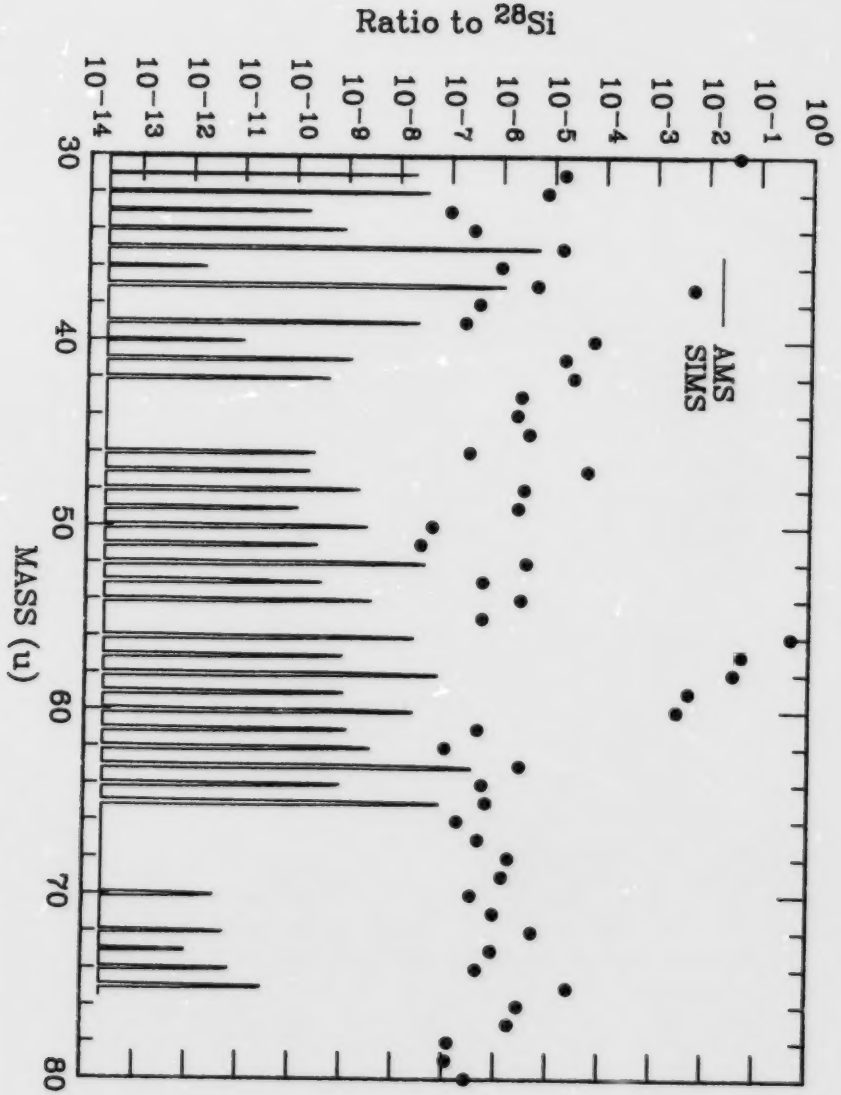
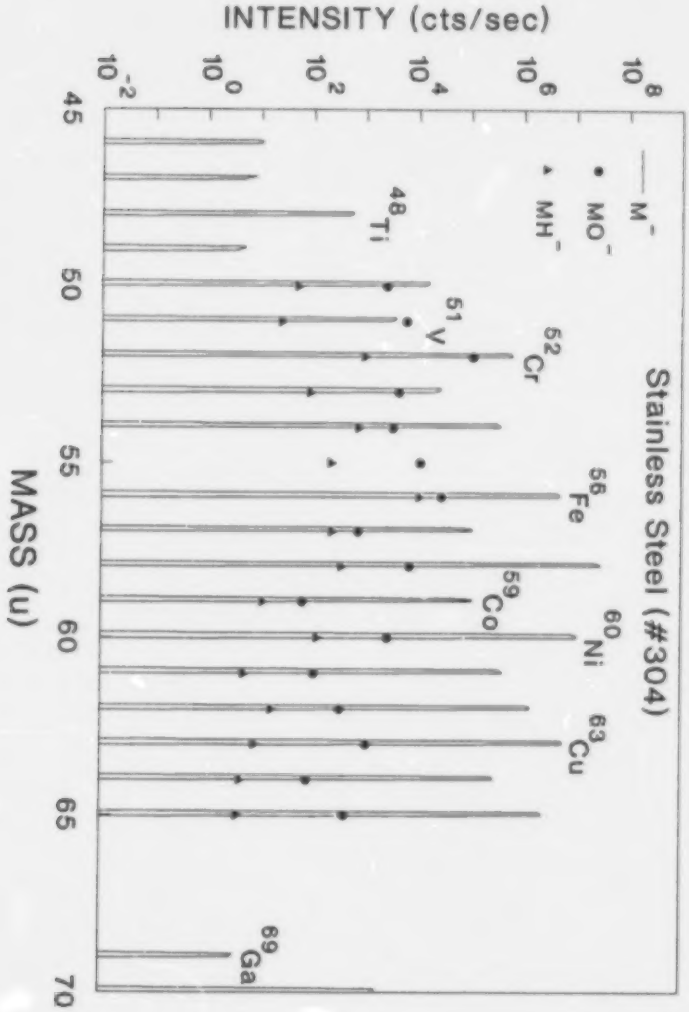


Figure 3. *AMS and SIMS (negative ion) analysis of clean Si.*

Figure 4. AMS analysis of a steel sample. Selected isotopes are identified. Injection of hydrides and oxides and analysis of the elemental fragments after dissociation allows the detection of ^{55}Mn, which does not form a negative ion.



evidence of a signal at mass 55 (^{55}Mn) in the negative ion spectrum. Injection of oxides or hydrides and analysis of the elemental fragments does allow detection of the Mn, however.

These results demonstrate feasibility of the system, but routine trace analysis requires construction of a "clean" ion source, and a joint UNT/TI project is underway to produce one. Design goals for the system include parts-per-trillion level detection for most elements, minimum Cs beam diameter near 10 μm, raster scanning for image generation, and depth profiling with depth resolution of about 10 nm. Magnetic analysis (90 degrees) of the Cs beam before sputtering, Si electrodes for ion optics (where possible), a Si based sample holder, clean Si slits and collimators, and ultra high vacuum construction are all being implemented to reduce possible sources of cross contamination.
Component testing is on-going at TI and UNT, and full source operation at UNT is tentatively scheduled for the third quarter of 1991. Although AMS is obviously attractive for trace analysis, there are many situations in which the ability to reject molecular interferences at ppm levels may be useful. As a practical matter, mass calibration of SIMS instruments at high resolving powers is not trivial. A survey of a sample looking for unknown constituents is therefore not easily performed in high mass mode due to the large number of signals which may be present, while AMS, which can furnish truly atomic spectra, will excel. Similarly, SIMS depth profiles through various material layers are often plagued by different interfering molecules at the same nominal mass as the sample structure changes. This application of AMS, while not requiring high sensitivity, may nonetheless provide extremely useful information about material structure in a much more straightforward fashion than SIMS. This is a major justification for the depth profiling capability being included on the UNT system.

AMS Science

One advantage of an automated, multi-element AMS system is its ability to quickly scan for anomalies at a variety of masses. A common assumption with AMS analyses is the instability of molecular ions stripped to a charge state of 3+ (or greater). Mass scans with pyrolytic boron nitride at UNT have detected unexpected peaks at masses 20, 21 and 22 which were later traced to the metastability of the B_2^{3+} molecular ion[13]. Variations in isotopic abundances for Ca contamination in Si samples were also traced to apparent metastability of the AlO^{3+} molecular ion[11]. Semi-empirical molecular orbital calculations furnish some support for these measurements[14]. Investigations into other molecular systems are planned with a goal of generating both interesting physics and a

practical procedure for avoiding the problem during trace analysis.

Automated mass scans have also furnished information about the process of negative ion formation. Analysis of mass spectra recorded from $CaCO_3$ has demonstrated the presence of definite peaks for the Ca and Sr isotopes, thereby verifying the formation of the Ca^- and Sr^- negative ions during sputtering[11] (these elements were long suspected of having an electron affinity of zero). Similar results have been reported by the Toronto group[15]. Since many elements form negative ions poorly, an understanding of the ion formation probabilities is crucial for general trace analysis. This process may benefit conventional radioisotope AMS as well. Efforts to detect ^{41}Ca led to the discovery[16] that formation of the KH_3^- ion is strongly suppressed relative to CaH_3^-.

An automated mass spectrometer can quickly search a variety of injected molecules over a broad mass range to investigate similar effects in other systems.

Advances in mass spectrometry have a history of impacting a variety of scientific disciplines, and this can also be expected for trace analysis of stable elements. For example, a measurement of double beta decay (Zn^{70} -> Ge^{70}) using AMS has been proposed by Tuniz[17], but the maximum halflife detectable depends directly on the Ge contamination in the ion source.

Preliminary measurements at their facility are limited by a Ge background in the ppb range. Further reduction of the Ge level has not been successful with the current hardware, but should be relatively straightforward on an instrument specifically designed for trace measurements.

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Development of ^{26}Al Accelerator Mass Spectrometry for Biological and Toxicological Applications

J. Barker, J.P. Day

Department of Chemistry, University of Manchester
Manchester M13 9PL, UK

P.V. Drumm, J.S. Lilley and G.W.A. Newton

Nuclear Structure Facility, S.E.R.C. Laboratory, Daresbury
Warrington WA4 4AD, UK

Aluminium is recognised as a toxic element. It is implicated as a cause of serious conditions in renal patients, and there is a possible link between aluminium accumulation in the brain and a form of senile dementia (Alzheimer's disease). Although uptake from food and water are important exposure pathways, there is so far little quantitative knowledge about gastrointestinal absorption of aluminium. This is partly the result of the lack of a suitable radioisotope.

Aluminium is also toxic to plants and aquatic life and is mobilised from soils by acid rain, with serious environmental consequences.

Radiotracer studies on Al are possible with ^{26}Al ($T_{1/2} = 0.716 \times 10^6$ y), but a comparatively large amount of this expensive radioisotope would be needed to measure by normal counting techniques. Use of conventional mass spectrometry is impracticable due to ^{26}Mg interference (inherent in all biological or environmental samples), but high energy AMS, resulting in fully stripped ions (Al^{13+}/Mg^{12+}), potentially overcomes this problem [1]. ^{26}Al is particularly attractive for isotopic tracer work in human toxicology because of its negligible natural abundance and low radiological hazard.

Previously, most ^{26}Al AMS measurements have been conducted using tandem accelerators at terminal voltages typically under 8 MV, and accelerating the simple $^{26}Al^-$ ion. Prevention of isobaric interference depends upon the instability of the $^{26}Mg^-$ ion.

We have used the 20 MV tandem Van De Graaff accelerator (S.E.R.C. Daresbury) to conduct AMS measurements on ^{26}Al. Stable (>5 hours) $^{27}AlO^-$ beam currents of ca 100 nA were obtained from a modified Middleton ion source, using alumina/silver source preparations of $<100\ \mu g$ [2]. At 17 MV, the Al^{13+} charge state fraction is ca 54%. ^{26}Mg-^{26}Al separation is complete. Determination of ^{26}Al is made by simultaneous measurement of $^{27}AlO^-$ beam current on an aperture, or by switching the inflector magnetic field to mass 43 and measuring $^{27}AlO^-$ on a Faraday Cup in the beamline before and after a sample run. Linear calibration (CV < 10%) was obtained over the range tested ($^{26}Al/^{27}Al$ ratios from 10^{-6} to 10^{-11}), and a detection limit of ca 10^{-18}g ^{26}Al (a ratio $^{26}Al/^{27}Al$ limit of 10^{-15}) was estimated.

An experiment was designed to determine a lower limit for gastrointestinal absorption of ingested aluminium under physiologically normal conditions of aluminium load [3].

Aluminium-26 (100 ng; 70 Bq) together with a negligible amount of natural aluminium (ca $1\mu g$ ^{27}Al) in sodium citrate solution was ingested by a human volunteer, and serial blood samples taken at 6, 12 and 18 hours. Analysis of this blood showed 95% associated with high molecular weight species (principally the iron-transporting protein transferrin) [2]. The lower limit of gastrointestinal absorption was determined to be 1%. This compares with values of 0.01% previously obtained by other experimenters using macroscopic quantities of aluminium hydroxide. In our experiments, the ingested aluminium was associated with citrate (to act as carrier), and there is a possibility that citrate speciation will enhance aluminium absorption. However, citrates and similar metal-complexing organic species are common components of the human diet, and our experimental conditions may not be unrealistic as a model for the gut uptake of aluminium organically bound in food and water.

Experiments are now under way to study possible abnormalities in aluminium absorption in Alzheimer and renal patients with aluminium overload.

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Application of AMS to the Biomedical Sciences

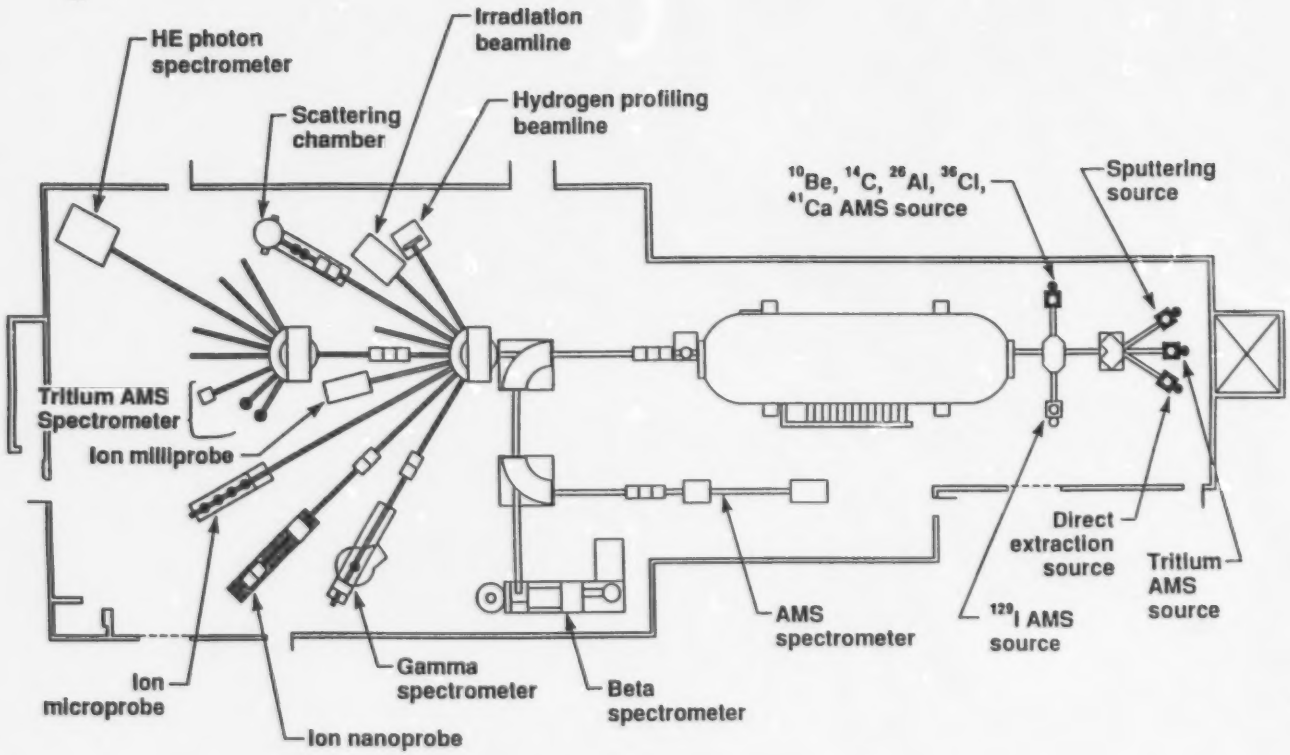
John S. Vogel

Center for Accelerator Mass Spectrometry
University of California, Lawrence Livermore National Laboratory
Livermore, California 94550 U.S.A.

Introduction

The possibility of using AMS in biological studies is noted by Keilson and Waterhouse[1] as early as the first AMS conference in Rochester (1978), and an overview of AMS and some possible applications of tracing metallic isotopes in biomedical research is published by Elmore[2]. However, the direct application of AMS to research in the biomedical sciences only began to appear in 1988-90, partially due to the influence of a biomedical AMS research group developed between the Physics Department and Biomedical Science Division at Lawrence Livermore National Laboratory in 1987. Indeed, the 1990 AMS conference heard five papers showing active research in biomedical sciences[3,4,5,6,7], the first such evidence since the initial Rochester conference. Our first successful use of AMS for detecting ^{14}C-labelled compounds in molecular biology has also been published[8], as has a technique for archaeological datings which arose from the synergism available in our biomedical AMS program.

The AMS facility (The Center for Accelerator Mass Spectrometry) grew out of a plan to construct a multi-purpose ion-beam facility in the Physics Department[10]. The needs and restrictions of AMS were of primary concern in the design of the laboratory, and no compromises were knowingly made to the quality of the AMS system in order to serve other users (Figure 1). The facility is built around an HVEC model FN accelerator from the University of Washington (their "injection" tandem), which had been the machine previously proposed for an AMS laboratory in British Columbia[11]. Beginning in 1986, Canadians have been involved in the design, construction, operation, and application to biomedical science of this facility, through the RIDDL AMS group


HE photon spectrometer
Irradiation beamline
Scattering chamber
Hydrogen profiling beamline
^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca AMS source
Sputtering source
Tritium AMS Spectrometer
Ion milliprobe
Direct extraction source
Tritium AMS source
AMS spectrometer
^{129}I AMS source
Ion microprobe
Gamma spectrometer
Beta spectrometer
Ion nanoprobe

which operated at Simon Fraser University using the FN accelerator at McMaster University. Initial testing of ideas for biomedical research were carried out at SFU/McMaster while the LLNL facility was under construction[12].

The Center began making AMS measurements in 1989, and a gross yearly breakdown of sample categories of ^{14}C measurements is shown for the two years (April to April, 'NSERC' years) in Figure 2. In the first year, standard known materials and background determinations were the single largest category. In the past year, two large geoscience surveys occupied the large fraction of time spent on ^{14}C measurements. Biomedical experiments were limited by the original sample preparation system, which has now been replaced with a batch-mode operation. We expect that the number of biomedical samples will increase 5-fold in the next year, and the number of geoscience ^{14}C samples will double, at least. Other isotopes will be measured for both fields, but the sample load for the other elements is not predictable at this time. The current state of the laboratory's isotope menu is given in Table 1. While the Center has embarked on exciting research in geoscience and other fields, only the biomedical research and its prospects for the future will be discussed here, as LLNL has a body of experience in this area which may be unique. While many of the detailed techniques for making these biomedical measurements resemble those used in the application of AMS to other fields, the biological tracing experiments differ substantially from the observational approaches of the earth science investigations.

These scientific programs in Biomedical Science and Nuclear Chemistry (i.e. geoscience) have been funded since 1988 through LLNL's Internal Research and Development Program. Both have matured to the point that external funding is expected to be able to carry the research costs in the near future. The facility support is still expected to be derived from LLNL programs.

Figure 1. *The floor plan of the CAMS facility. The AMS injection magnet and the AMS analyzing magnets are closest to the accelerator. All other users obtain their ion beams from one of the two large switching magnets (re-built used cyclotron magnets). The tritium AMS analyzer is part of the second switching magnet. Ion milli-, micro-, and nano- probe lines come from the first switching magnet. The two micro-analysis techniques of AMS and tomographic micro-probe imaging are exceptionally compatible, and our plans include dedicating the laboratory increasingly to these two applications.*

Isotope tracing in molecular biology

The Biomedical Sciences Division of LLNL is particularly interested in the role xenobiotics play in initiating mutations (benign, beneficial, or fatal) in cells. We use various hosts, from cell lines to mice and rats, in order to detect the effects of toxins, mutagens, carcinogens, or chemotherapeutics in living systems. The biological effects of these materials are quantified as a function of how much of the xenobiotic entered the cells and/or caused damage to the genetic content of the cell nuclei. One measure of this chemical invasion is obtained by counting the number of DNA adducts (covalently bonded foreign

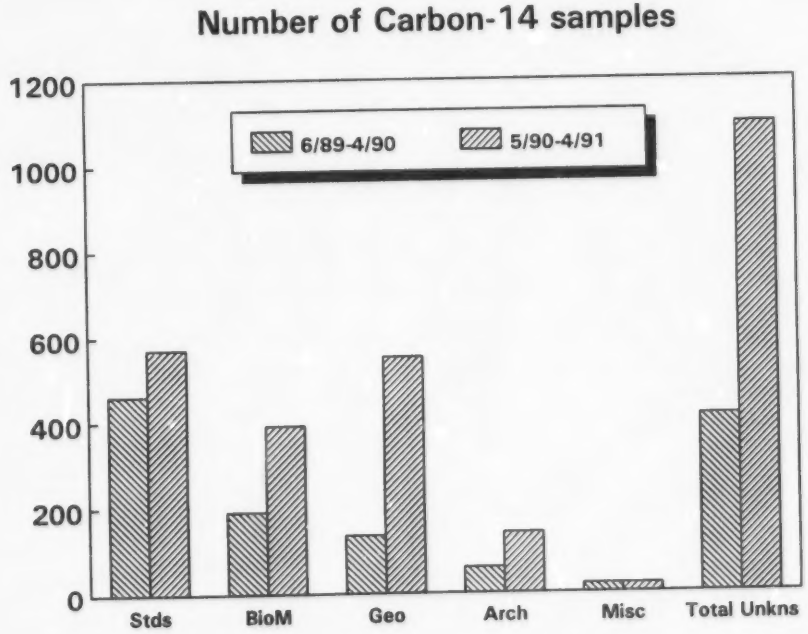


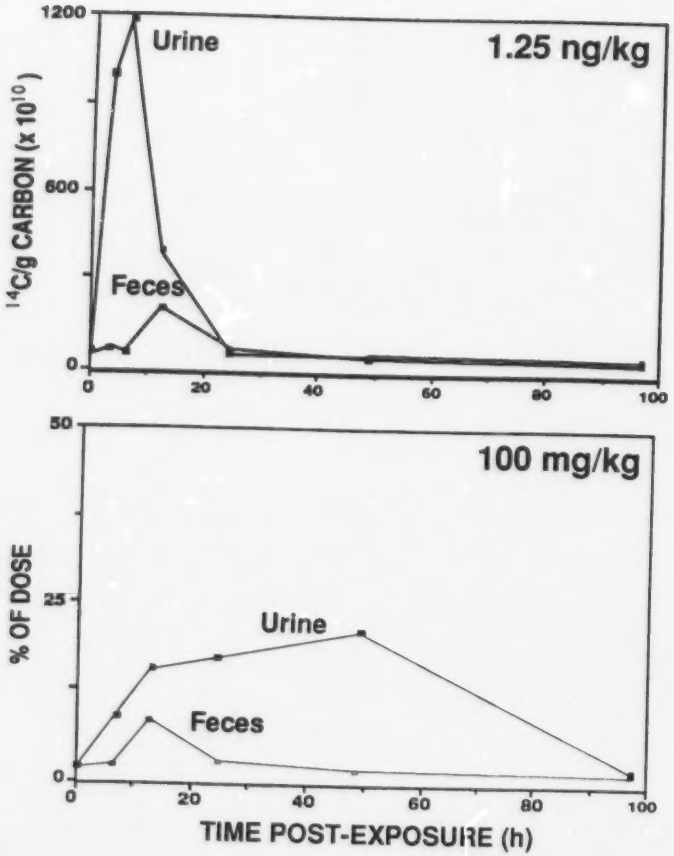
Figure 2. *The number of ^{14}C samples measured (to "some" degree of precision) in our first two years of operation. The laboratory is primarily funded by Director's discretionary grants in biomedicine and nuclear chemistry. The sample split reflects these realities.*

molecules on the bases of DNA) as a function of the applied chemical dose. AMS allows us to obtain direct stoichiometric quantification of these adducts through measurement of the ^{14}C present in purified DNA after exposure to ^{14}C-labelled carcinogens. Radiocarbon is presently the isotope of our choice for detecting these adducts, since the xenobiotics are invariably organic chemicals in which a ^{14}C atom can be incorporated in a non-labile molecular location without causing any change in chemical behavior. Similarly, tritium can be easily incorporated into a wide variety of chemicals, and the value of tritium AMS in quantifying molecular interactions is just now being explored. Initial efforts in sensitive detection oftritium are encouraging, but no biomedical results have been obtained.

While our emphasis has been on ^{14}C, with its nearly universal applicability, we are also interested in some of the heavier isotopes which can be detected with AMS. Chlorinated hydrocarbons are a ubiquitous class of manufactured chemicals, some of which have been shown to become concentrated in adipose tissue over long periods of low exposure and are harmful to mammals. We are developing an ultra-sensitive (we hope) radio-immuno-assay for detection of heptachlor and dioxin using ^{14}C-labelled competitors, but ^{36}Cl may have a role to play in the understanding of this molecular family. Selenium-79 may also have applications in immuno-chemistry, since some of the atoms in the di-sulphur bonds which control the geometries of antibodies can be replaced with ^{79}Se. This essential element may also be kinetically traceable at levels well below toxicity using this isotope rather than the more common, short-lived ^{75}Se. Iodination of proteins is a well known art, primarily because the short lifetimes of the useful iodine isotopes require production of the iodinated proteins close to the use of the compounds. Besides its several environmental and geological uses, the very long-lived isotope, ^{129}I, could improve the comparability of experiments using iodinated proteins. The proteins could be available with long-term stability for repeated or linked experiments. Others have begun to explicate the biokinetics of elemental aluminium[6,7] using ^{26}Al. While we have useful measurement capability for detecting ^{26}Al, it is an element which does not presently fit into our biomedical interests. Calcium-41, however, will be of immediate interest to us once we obtain sufficient energy from the accelerator and begin to develop our capability for detecting this isotope. It may prove useful in understanding cell regulation, as well as being a tool for studying bone resorption and osteoporosis[5]. Although we are presently emphasizing use of ^{14}C in our research, we expect that isotopes from masses 3 to 129 may eventually play larger roles in biomedical research. AMS facilities based on the large tandem accelerators such as CAMS, provide the needed tool to explore a wide range of biomedical tracers.

Our experiments with low doses of environmental carcinogens reflect the protocols which will become a common part of biomedical AMS. In previous work with mutagens which arise from the cooking of meats, the chemical equivalent of many kilograms of cooked beef had been fed to mice as purified, radio-labelled compound in order to determine the most basic pharmacokinetic lifetimes of this class of dangerous carcinogens. At present, we are experimentally determining the complete biokinetics of one of these food mutagens: PHIP, or phenylimidazopyridine. Original experiments[13] in kinetics were done at a chemical dose of 100mg of PHIP per kilogram of body weight (100mg/kg), equivalent to the PHIP content of 100 million fried hamburgers. The compound was found to be evacuated through the urine over a period of 2-3 days. The faecal removal was complete in 1 day, within the counting detection of the scintillation system used (30dpm). We have recently repeated the experiment using a more relevant chemical dose of 1.25ng/kg, equivalent to the amount of PHIP which could be made during the preparation of a single large hamburger. The faecal evacuation of the compound is found to be the same at the two divergent doses. However, as shown in Figure 3, the urinary excretion is very different from that in previóuswork. Clearly, there is a rate-limiting process in the metabolism and excretion of this compound which does not become saturated at normally relevant doses. Since biological risk is calculated as a function of the exposure time of a given organ, the risk in consuming this chemical cannot be directly extrapolated from the evidence of larger dose experiments. The low chemical dose is obviously easy to detect using AMS, and in fact, we are determining the entire "box model" of the mouse with respect to this compound. We are measuring the concentration of [^{14}C]PHIP in the two excreta, in the blood, and in eleven different tissues or organs, all at 10 time points after exposure. The entire experiment is independently repeated 3 times. Thus, this experiment entails at least 420 ^{14}C measurements.

Figure 3. *The relative amount of a labelled carcinogen (PHIP) excreted from mice at various time points after exposure can be derived from the ^{14}C measurements of the urine and faeces. Our recent work was done using the amount of PHIP expected to be in a single large hamburger. Previous measurements had been done with the equivalent of "over 100 million". hamburgers. The difference in the time profiles has important implications to calculations of cancer risks.*



AMS

Scintillation counting

Experiments such as these do not strain the capacity of our AMS system, since each measurement takes only about 3-5 minutes (including replication). We need determine the ^{14}C concentration to only 1-3%, and the ion source provides 20-60 μA of $^{12}C^-$. However, this and other experiments do severely strain the sample selection and preparation process.

Preparation of samples - the log-jam

Since we are and will be involved in geoscience experiments and surveys which require 100-600 ^{14}C measurements, the sample preparation problem is not just a biomedical one. We plan to have at least 2 other injection legs and ion sources, but even with the present capacity of our high-intensity ion source, sample chemistry is the most rapidly expanding part of our labour pool. In biomedical experiments, the researcher defines the carbon to be analyzed through dissection and/or chemical purification. Thus, unlike in the geosciences, there is no pretreatment at the AMS facility, and the sample is "merely" combusted and graphitized. For all of our ^{14}C efforts, we have a 10 reactor "cold" manifold, an 8 reactor "cold" manifold, and a 4 reactor "warm" manifold. We will soon operate a graphite 'franchise' at Angelo State Uni. (Texas) with a 10 reactor "cold" system. Further, we are aiding some of our bigger collaborators and clients in constructing their own graphitizers to suit their through-put and sample types. Of course, we require that all of these graphite systems be operated by knowledgable people who understand contamination and background problems. Each remote graphite system must send in its own standards and blanks. All make filamentous graphite on a cobalt powder substrate[14,15]. However, the preparation of graphite from a large number of biomedical samples which may have ^{14}C concentrations ranging over 5 orders of magnitude cannot be safely done in the usual reactors connected to a common manifold[12]. Instead, we have developed modifications to a sealed-tube method's of producing filamentous graphite. Titanium hydride is added to the zinc powder reductant in a sealed tube with a separate cobalt catalyst. The entire tube is uniformly heated in a furnace for 5-6 hours to form the graphite on the cobalt[17]. The hydrogen released from the hydride appears to block carbonyl production and the deleterious transfer of zinc to the cobalt-graphite sample. The number of tubes which can be simultaneously processed is limited only by the size of the furnace (and the ability of the staff to catalog all the sample data!). We have processed (combusted and graphitized) up to 40 per day. To avoid the contamination of samples by gas exchanged from manifold walls, a completely disposable manifold has been developed from plastic 'Y' joints and Tygon tubing. A new mini-manifold is

used for each sample, at a per sample cost of = $1.50. We have handled >500 Modern material followed shortly by 0.01 Modern material using this system. We will also use this process in environmental surveys as well, where there are many samples at nearly contemporary ^{14}C concentration for which 1.5% precision is sufficient.

Biological and chemical sample preparation

Even if we have solved the problem of graphitization of the combusted sample, there are still a great many procedures which can, and do, contaminate the sample during the biological separation and chemical selection of the fraction of carbon to be analyzed. This was a problem at our own facilities at LLNL, but we have evolved procedures to minimize such contaminations. However, we have found that working with samples from other biomedical institutions requires constant evaluation and correction of the procedures in their facilities. At a minimum, we insist that one or two of us go to each collaborator's laboratory and review with them the possible paths of contamination. Initially, any animal facilities and laboratories which are to be used must be "swiped" and checked using AMS. Usual radiation safety detectors are far too insensitive to detect levels of ^{14}C which are disastrous to AMS samples. Measuring the ^{14}C in a small clipping of hair from animals is a good way to integrate their exposure over time to internal and external (cages) sources of contamination. From the start, we must have separate work areas for "hot" and "cold" work. The compounds which we are tracing in living hosts usually arrive at 1-50Ci/Mole concentrations, or several micro-Moles of ^{14}C in a vial! The initial step in the "hot" area is to carefully dilute these compounds. Injections or applications of the diluted, but still "hot", compound to the host must also be done at a work station which will not be used in later procedures. Lab bench covers, paper wipers, latex gloves, and disposable lab coats must be used "to excess" in order to prevent small, inadvertent contaminations. Once a sample is biologically defined, it may require further chemical characterisation. Large shared instruments, such as gas chromatographs, cannot be used because of possible exchange between samples. Instead, disposable methods of chemical definition are used. For example, kits are available for separating nucleic acids on small disposable columns, and there are single-use centrifuge filters for molecular weight separations. At $2 per sample they are inexpensive compared to the entire processing of a given sample.

The most pernicious source of contamination is the work habits of the researchers and technicians who have handled radio-tracers previously. The "background" in a usual biochemical scintillation counter is about 30cpm, due

to small spills, poor arrangements, etc. With these backgrounds, it is not possible for experienced technicians to know what common laboratory practices will lead to contamination which is large by AMS standards. It seems helpful, if socially undesirable, to have a paranoid AMS operator watching and commenting on handling procedures.

The pent-up demand

Even with the obstacles of contamination and sample preparation, AMS has benefits to bring to biomedical science which make the efforts worthwhile. Our group has presented talks and posters at conferences dealing in cancer research, toxicology, environmental mutagens, etc. The response has been consistently one of extreme interest leading to many requests for collaborations. The sensitivity we display in our detections of molecular interactions cannot be gained using any other method. We cannot now begin to keep up with the demand for measurements, even with the expected expansion to 1000 or more biomedical measurements in the next year. Some of the projects on which we are working and/or for which we are submitting proposals are listed in Table 2. While we prefer not to disclose the exact collaborators, they include researchers from the US National Cancer Institute, a Scandinavian research center, commercial research centers, and University of California campuses. One project involves up to 300 samples from a Canadian research institute. The original experiment was performed at doses too small to detect conventionally. When the Canadian saw one of our biomedical presentations, he negotiated a collaboration/contract with us for the measurements of his stored tissues. Another collaboration will focus on the value of *not* finding adducts of a labelled compound. It is of great value to discover early in the commercial synthesis of a compound whether or not it is genotoxic. Figure 4 shows that TCDD ('dioxin') does not bind directly to the DNA in murine hepatocytes. The known effects of dioxin result from enzyme induction, but our data are the first to test for direct binding at relevant levels. The highest dose level in the Figure represents a nearly fatal dose, and carbon in the dioxin is 96% ^{14}C. Our proposed biomedical collaborations and grant requests total to over $1.2M in the next fiscal year.

Yes, one of the listed projects involves collaboration with a major manufacturer of diesel engines. By 1994, the particulate emission from diesels must be reduced to new lower standards in California. This is a short time scale to change engine manufacturing methods, and is a distressingly short time frame when one does not even understand the general source of the carbonaceous particles. Working on the assumption that the box model of a diesel engine would be even simpler than the box

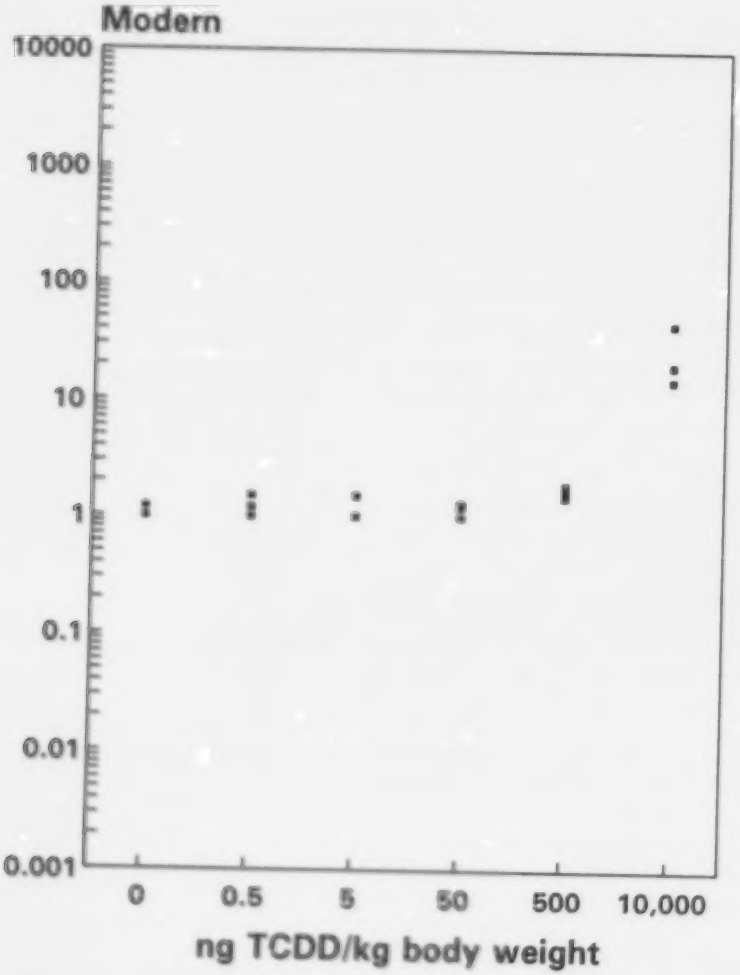


Figure 4. *The ^{14}C content of murine hepatocyte DNA after exposure to fully-labelled [^{14}C-U]TCDD or dioxin. Although the liver as a whole might contain enough ^{14}C to make it 1 million Modern, the DNA does not show any adducts from the labelled dioxin, except at the highest (nearly lethal) dose. Chemicals which do not bind directly to DNA are not genotoxic, but they may be enzyme inducers.*

model of a mouse, we are applying ^{14}C tracers in diesel fuel and lubricants in order to understand the source of the particles. Contract values ranging in the upper 6 figures are expected.

Is biomedical AMS for every lab?

While I think that there are enough interesting experiments in biomedical tracing to involve several AMS facilities, the AMS community has been slow to develop methods of interacting with experimental biochemistry. We think that our new sample protocols allow us to perform these experiments easily; but we, too, remain cautious. The cost of contaminating a sample has been minimised to just the biological and chemical sample preparation. We have not found lasting danger to our highly modified ion source[18] or to other components of the AMS system. Still, AMS operators may remain wary.

We have established another experimental program at LLNL which may allow even the most cautious to join in biomedical research. We have shown that sensitivity for detecting molecular interactions can be increased by using methanotrophic bacterial hosts which have been grown on natural gas. We have also begun a project to deplete the ^{14}C content in our most usual host: the C57BL/6 mouse. A mouse diet has been developed in which the fibrous portions are made of contemporary materials, but the protein in the diet is derived from natural gas. Just the growing and breeding of these mice has become an interesting study, as we note any differences in growth rates, litter sizes, etc. These data are important because our derived diet is much richer in protein than normal mouse diets. Very little data exist concerning the effects of such a diet. The Lazarus Project (to raise the "dead") is now in its second generation of both the control and the depleted lines of mice. The control mice remain contemporary. However, the depleted mice are apparently 11,000 years "old" at 0.25 Modern.

As the depletion in ^{14}C progresses, these mice will become more valuable in:

increasing the sensitivity of biomedical assays;

permitting experiments, especially nutritional studies, to be performed with nutrients, vitamins, carcinogens, etc. having only natural ^{14}C content; and,

perhaps, making biomedical AMS available to labs with even the fussiest physicists.

Conclusion

From the standpoint of the Biomedical Sciences Division and CAMS at LLNL, AMS has a bright and diverse future in radio-isotope tracing. Such work requires a dedicated amalgamation of AMS scientists and biomedical researchers who will re-design experimental protocols to make the most of the AMS advantage while minimizing the danger of catastrophic contamination.

The nature of many biomedical efforts requires a fast turn-around on numerous samples measured to only "moderate" precision. These can be provided at a "high precision" lab by using an intense ion source and lowering the number of repeated measurements. However, a moderate precision laboratory, built from a used machine with an intense ion source, could also be a world leader in these measurements. Sample preparation must be maximized for throughput and isolation, perhaps at the expense of small isotopic fractionations. For many of us who have engaged in the hunt for the best precision, this appears antithetical. The exquisite crafting of each AMS measurement here gives way to useful rapid, but trustworthy, results. For example, our radio-immune-assay project was at a complete halt, biologically, while the accelerator was being worked on over several weeks. The next step in the assay analysis could not be begun until we had the results from the last experiments. Similarly, mice and other living hosts must be used with efficiency and timeliness. Experiments using animal hosts must have quick results in order to rapidly find the maximal animal protocol. We will now devote every Monday afternoon and evening (night, too?) to make the AMS measurements which keep the biochemical research on track.

Finally, funding agencies must appreciate the value and the need for extreme interdisciplinary interaction in this application. Even the lower-voltage AMS facilities appear to some granting bodies as too large an operation for routine biomedical research. However, CAT scanning, PET scanning, and NMR imaging arose from unwieldy physics experiments to contribute heavily to biomedical science in their present form. And so will AMS. We have two spare EN accelerators and spare FN parts ready to put in place when it does.

Acknowledgments

An attached list shows the scientific staff at CAMS. The results used for examples in this presentation are due to the efforts of all of them as well as our technical staff. The biomedical research, in particular, arises from the expertise of Ken Turteltaub, Jim Felton, Bart Gledhill and Larry Stanker. I am grateful that they are so understanding as to allow a physicist to learn their language and to assist in their exciting research. The work described here was performed under the auspices of the U.S. D.o.E. by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

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Table 1. **CAMS is actively measuring 5 isotopes, 2 more are on order**

^{14}C: measure about 40 samples and standards per day -- best accuracy 0.5%, more typical 1-1.5%

^{10}Be: calibration completed, background $5x10^{-15}$, accuracy 2-3%

^{26}Al: calibration in progress, background $4x10^{-15}$, accuracy to be determined

^{36}Cl: calibrations in progress, background $3x10^{-15}$, accuracy to be determined

^{3}H: calibration in progress, background $4x10^{-14}$, accuracy to be determined

^{41}Ca and ^{129}I: calibrations to begin in next 2-3 months

Table 2. **Projects from a few of our recent requests for collaboration or service**

Quantification of DNA adducts in primate lymphocytes - draw small blood samples from valuable monkeys

Drosophila DNA damage and repair - extreme sensitivity through depletion of host Pharmacokinetics of 1-Me-Phen from "failed" experiment - dose too low to be measured by scintillation

DNA de-amination and tumorigenesis

Mutagenicity of acetaminophen - is a common cold remedy mutagenic?

Screening of chemicals and drugs to find non-mutagenic forms - demonstrate lack of DNA binding

Pharmacokinetics and adduction of benzene and TCE - EPA study of 'SuperFund' toxic waste sites

Source of soot in diesel engines - collaborative effort with major manufacturer

Principle Scientific Staff of CAMS

CAMS L-397

Bertsche, Kirk J.
Caffee, Marc W.
Davis, Jay C.
Finkel, Robert C.
Heikkinen, Dale W.
Hornady, Robert S.
Proctor, Ivan D.
Roberts, Mark L.
Southon, John R.
Trumbore, Susan E.
Vogel, John S.

BIOMEDICAL L-452

Felton, James S.
Gledhill, Barton L.
Turteltaub, Kenneth W.
Stanker, Lawrence.

V. Existing Facilities and the Level of Activity in Canada

The Economic Context

David Brez Carlisle

Environment Canada, Ottawa, Ontario K1A 0H3

There are currently six dedicated fully operational accelerator mass spectrometers around the world (a seventh is currently completing testing), together with a larger number of accelerators which are used for part of the time in AMS. In addition there are more at various stages of construction or planning. China alone is building four machines. The sole dedicated Canadian machine was the third to be built and was first planned in 1978. Even at that time, when the money available for science in Canada was greater and more accessible than now, it was difficult to fund the machine. In fact, NSERC, Environment Canada, the Department of Energy, Mines and Resources and the University of Toronto all contributed funds; no one organization was able to fund it totally.

Today funds for science are more difficult to obtain than ever, and it will be necessary to make a strong case indeed, if another AMS facility or machine is to be funded. Sylvia Ostry, formerly President of the Conference Board of Canada, is on record as stating that Canada's spending on research and development ranks second-lowest among major industrialized countries and is slipping badly behind a growing number of developing countries. All scientists complain about the perennial lack of funding for science in Canada, but few hard figures have ever been produced. To that end, I have compiled the accompanying graphs from publications of the Organization for Economic Cooperation of Development (OECD), an organization of some 24 of the more highly developed nations which have a free-market economy.

Figure 1 shows that Canada is among the lower nations in science spending expressed as a percentage of the Gross Domestic Product (GDP), barely ahead of Yugoslavia, Spain and Iceland. The position is even worse when we rank government expenditure as a percentage of GDP (Figure 2). Indeed, on this index Canada shows a poorer performance than India. Another index is the ratio between the value of the exports of scientific instruments and the value of the imports (Figure 3). Canada

exports only about a third as much as it imports, ranking with Portugal in this regard. Finally, Figure 4 presents the trends in science spending in Canada and two other nations over the last few years, expressed once more as a percentage of GDP. In the USA this has remained steady; in France there has been a steady rise in science spending. In Canada, after a slight rise from 1983 to 1984 there has been a steady decline. In fact the situation is worse than appears at first glance, for, starting in 1984, Canada began for the first time to report as "science spending" some items (such as research into the humanities and social science) which are not included by other countries. If Canadian reported spending is corrected to make it uniform with the other countries shown in this graph, then the decline in Canadian spending on the "hard" sciences becomes even more evident.

In this climate funding will be even more difficult to obtain than it was for IsoTrace in 1978, especially as most grants are given for a maximum of three years. Experience has shown that it takes four years - sometimes longer - to commission an AMS facility.

The decision must be made at this meeting whether to abandon AMS in Canada or to move forward. The *status quo* is no longer a viable option. Some current equipment at IsoTrace is nearing the end of its useful life, and merely maintaining current expenditure levels will lead to the demise of our existing Canadian laboratories. The participants in this workshop, the users of AMS, must decide where we want this all to go. Two main questions must be addressed:

> Should AMS capacity in Canada be expanded or curtailed?
>
> How best should this be brought about?

The presence of non-Canadian visitors at this workshop will I hope produce an international view of where we should going in AMS in Canada, as well as a national consensus.

Fig. 1 Gross Domestic Expenditure on R & D as a percentage of GDP (Most recent values - Source: OECD)

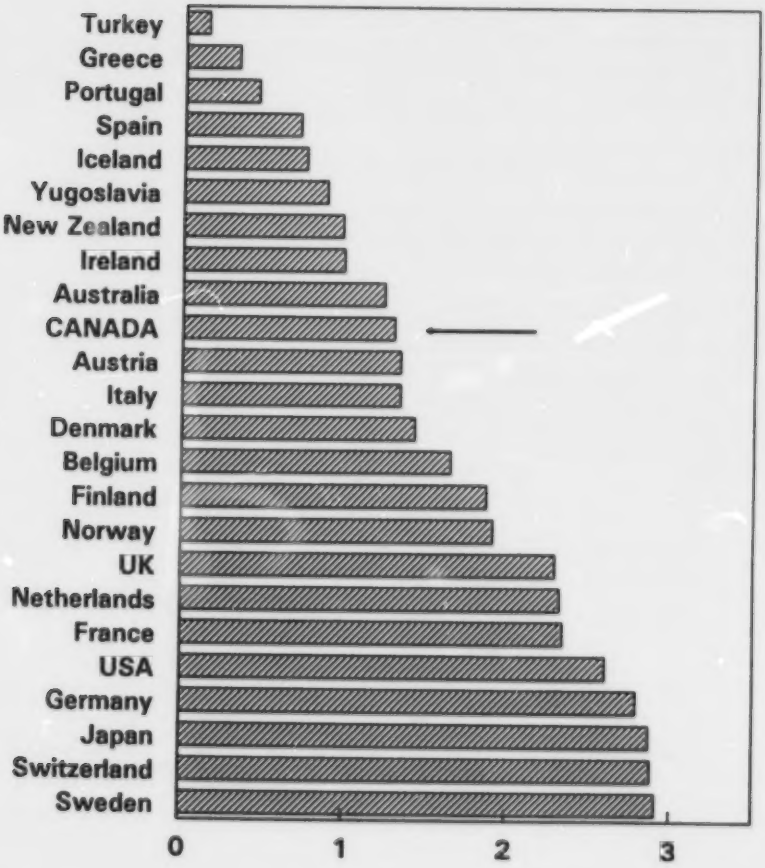


Fig. 2 Government Expenditure on R & D
as a percentage of GDP
(Most recent values - Source: OECD)

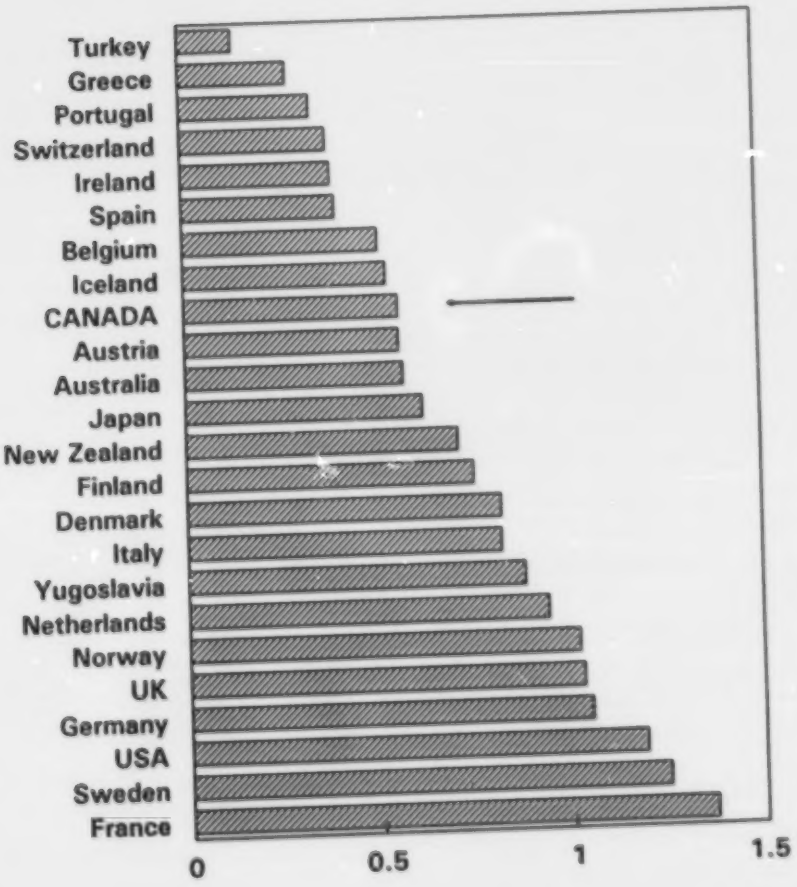


Fig. 3 Export/Import Ratio
of Scientific Instruments
(Source: OECD)

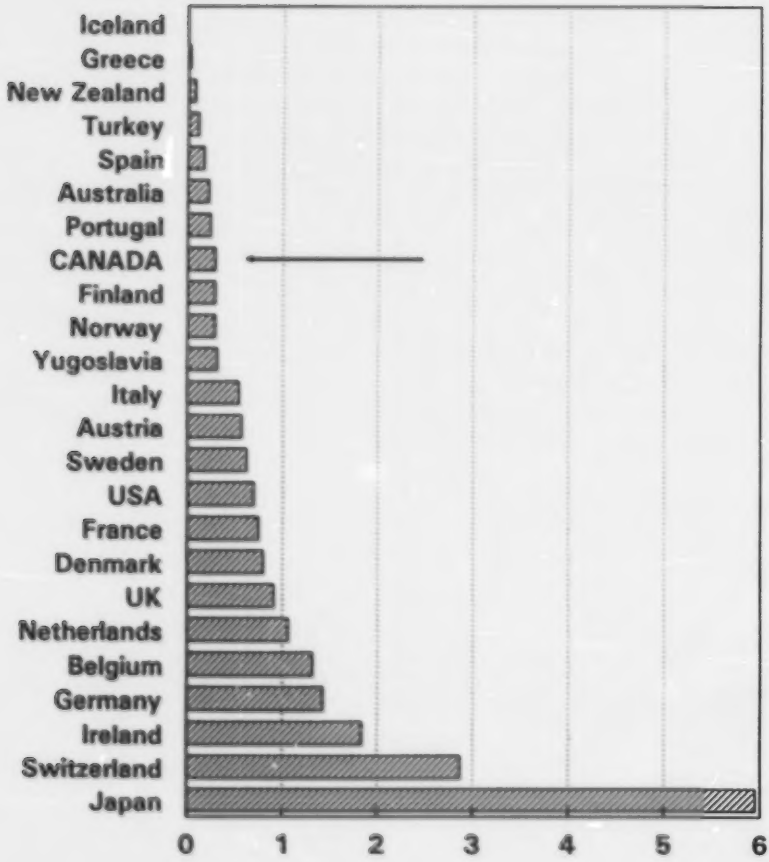
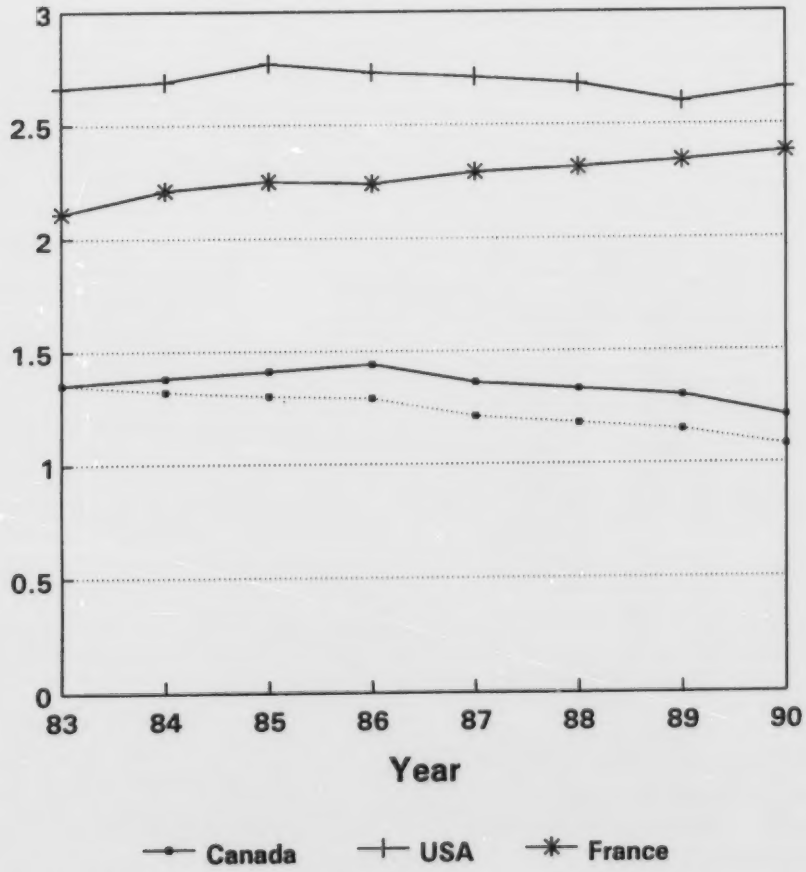


Fig. 4 Gross Domestic Expenditure on R & D as a percentage of GDP (Source: OECD)



AMS at Chalk River Laboratories

H.R. Andrews, R.M. Brown, R.J.J. Cornet, W.G. Davies, B.F. Greiner, Y. Imahori, V.T. Koslowsky, J. McKay, G.M. Milton and J.C.D. Milton

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario K1J 1J0

Introduction

AMS measurements of ^{14}C in natural samples were carried out with the Chalk River MP Tandem from 1978 until the installation of the new TASCC (Tandem Accelerator Superconducting Cyclotron) facility began in 1982. This program was reviewed in reference 1.

The installation of TASCC involved a total transformation of the laboratory. The facility now has nine new target areas, a new beam transport system and two new ion source decks. In addition, the MP tandem has been upgraded for 15 MV operation. Now that this project is complete, the Chalk River AMS program is being re-established to measure ^{36}Cl in hydrological and other samples of scientific interest. Other isotopes will be considered at a later date depending on the interests of those involved.

In this short presentation, I will give a brief overview of the facility followed by a status report on our present program for ^{36}Cl. I will end with a description of our longer-term plans and the possible role of outside participants in our program.

Figure 1. *Overview of the Chalk River Laboratories TASCC Facility*

The TASCC AMS Facility

Figure 1 shows an overview of the entire TASCC installation including the ion sources, Tandem, cyclotron and final target facilities. The bypass line allows delivery of Tandem beams to all target locations in the event that cyclotron energies are not required. The present AMS program involves the use of the Tandem only. Figure 2 illustrates schematically those parts of TASCC that are used in the AMS program. In addition to the standard features of the accelerator and beam transport system, a velocity filter has been installed in the by-pass line and the last dipole is being operated as a gas-filled magnet to suppress the ^{36}S count rate during ^{36}Cl counting. More details of the operation of the system are given in reference 2.

Present Status of the ^{36}Cl Program

Since the results presented in reference 2, successful measurements have been made of a number of standards, backgrounds and unknowns from water samples taken from the environs of the Cigar Lake uranium deposit. Our accuracy is limited to about 10%. Efforts are underway to identify and fix the accelerator parameters responsible for these residual instabilities. The present background limit appears to be around $5x10^{-14}$; it is not yet certain whether the observed background is true ^{36}Cl or misidentified ^{36}S and ^{37}Cl. Substantial progress in reducing the ^{37}Cl background has been made by improving the aperture system in the injection region and by improved operation of the velocity filter.

The gas-filled magnet has been very successful in reducing the ^{36}S rate in the counter, but it has introduced a small but troublesome flux of degraded ^{36}S particles that are harder to separate in the detector. It is hoped that the installation of baffles in the magnet box and improvements in detector performance will resolve this problem.Recently encouraging results have been reported by R. Middleton (private communication to A.E. Litherland) in the reduction of ^{36}S at the ion source. Many laboratories have used AgBr with some success as a coating material to prevent the Cs^+ beam from sputtering metal surfaces. Middleton has fabricated the whole sputtering cathode from AgBr with a small well in the centre for the AgCl sample. He has found ^{36}S:^{35}Cl ratios of $5x10^{-11}$ to $7x10^{-12}$, which result in very modest ^{36}S rates in the final detector.
We have recently tested a prototype multiple sample, spherical ionizer sputter source built by John Southon at McMaster and kindly given to us for use at Chalk River. The first test was very encouraging particularly in terms of memory effects, which have been significant for Cl in this source genre. On two occasions, after several hours of

operation with ≤ 5 μa of Cl^-, the mass 35 beam seen from a Cu sample dropped to ~ 1 na on the time-scale of a couple of minutes. Based on these first tests this source or a descendant of it looks ideal for ^{36}Cl and other isotopic measurements.

Chalk River AMS in the Longer Term

The underlying motivation of the AMS program at Chalk River has been to develop techniques for the study of problems associated with the management of nuclear waste. With dedicated facilities for ^{14}C, such as IsoTrace, in operation, we have turned our attention to ^{36}Cl - an isotope of great interest for hydrology and surface feature dating, and an isotope that requires a large accelerator for its measurement. Once ^{36}Cl capability is fully established, we intend to explore other long-lived isotopes, ^{32}Si in the first instance. Here our gas-filled magnet should be of particular value. Another isotope under consideration is ^{99}Tc, an important product of nuclear technology, which has potential applications to ground water dating also. TASCC is a national facility with most of its research programs involving collaboration with Canadian university faculty and students, in some cases with jointly-funded equipment. Our program is similar, in that we encourage good scientific collaborations and would welcome active participation in the research, including graduate students and research associates who might spend substantial periods of time at the laboratory.

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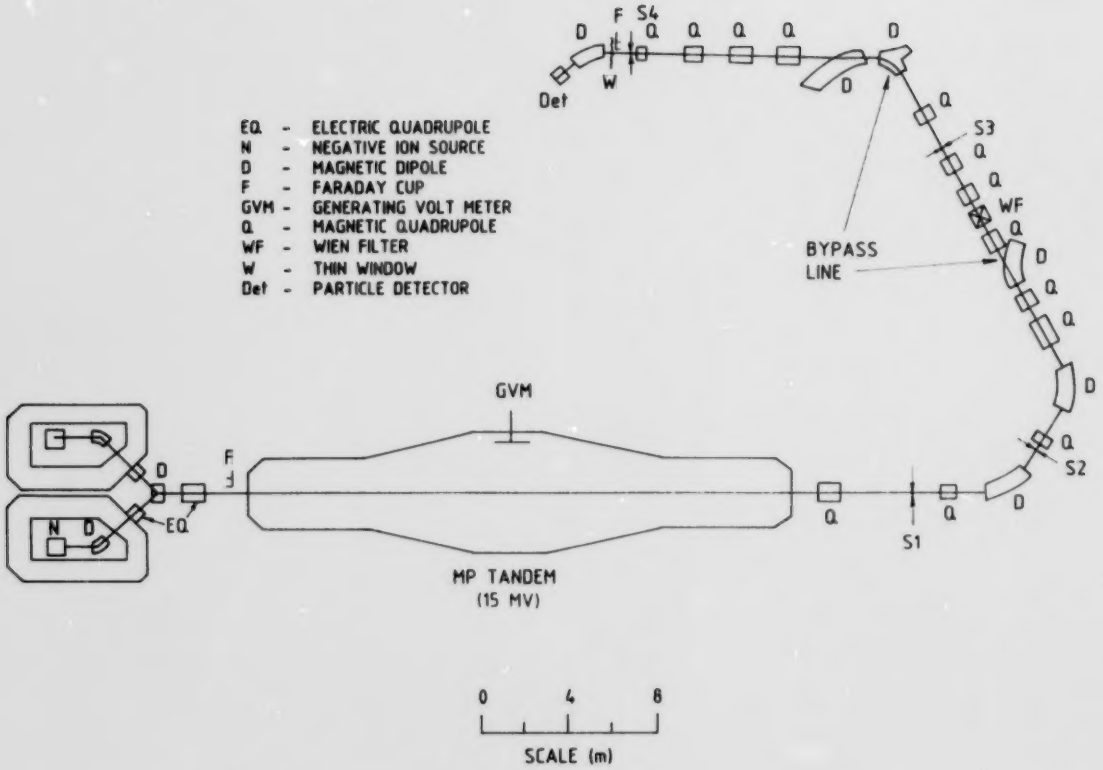


Figure 2. *Schematic diagram of the Chalk River AMS System.*

Accelerator Mass Spectrometry at IsoTrace - Present Capabilities and Future Possibilities

A.E. Litherland, J.C. Rucklidge, R.P. Beukens, W.E. Kieser and L.R. Kilius

IsoTrace Laboratory, University of Toronto

Summary

The current analytical capacity of the Accelerator Mass Spectrometry (AMS) system at IsoTrace is approximately 500 ^{14}C samples, 300 ^{129}I samples and 200 platinum group element samples per year, along with the provision of about 900 hours of accelerator time for research and development usage. Demand for the above services is increasing and interest in new services has been identified. An accuracy of 0.25% in ^{14}C dating has recently been demonstrated[1].

The existing equipment is aging and some major components will require replacement within several years just to maintain the present level of service. Volume of service on the present machine can be increased to a certain extent with the purchase of more efficient peripherals; however, for greater than a 60% increase in overall usage, the purchase of a second system may be required.

Future plans must be flexible to take into account the fluctuations in user research needs and the developments in AMS technology. Participants in the AMS Workshop are asked to contribute their thoughts about, and, if possible, their quantitative projections of the need for AMS services in their research discipline and on the relative priority that should be assigned to these needs within the Canadian context. In addition, research in the fundamentals of AMS must be carried out and new apparatus and techniques will need to be developed. The location, scale and funding sources for these activities must be determined.

A description of the technical options is included as an appendix to provide an indication of the scale of capital funding that may be required and examples of the level of service that such funding could provide.

The Current Status of the Laboratory

a) *Analytical and Research Capacities*

As it presently exists, the IsoTrace Laboratory provides AMS analyses for ^{14}C, ^{129}I and the platinum group elements (PGE), and operates equipment for basic research in physics (and chemistry) and for the development of new AMS techniques. The current capacities for each of these activities are: for ^{14}C, about 500 samples per year; for ^{129}I, about 300 samples per year; and for PGE, about 200 samples per year. This leaves approximately 900 hours of spectrometer time available for research and equipment development and a further 900 hours for spectrometer maintenance. To a certain extent, these capacities can be interchanged, subject to the conditions outlined below.

b) *Demand for services*

Demand for ^{14}C analyses presently exceeds the production rate by approximately 20%. This rate is limited by the time available on the spectrometer. With moderate engineering effort and capital ($10-20k), throughput could be increased to match the current 20% higher sample arrival rate; however, further significant increases would require an increase in staff and equipment in the sample preparation laboratory, major improvements to the ion source and injection system of the spectrometer and improvements in the accelerator voltage control system.

Demand for ^{129}I and PGE analyses currently uses only about 30% of the time available for these services. However, both of these have been available for only one year and interest in them is growing. The problem in this area is that a minimum level of activity must be sustained in order to keep the skilled technical staff required to prepare samples. Some active searching of business in this area has begun in North America and, with the assistance of the Department of External Affairs and International Trade Canada, in Europe, but more is needed so that these services can be continued.

c) *Requests for other services*

Interest in other AMS services has been noted from two quite different fields: the analysis of ^{26}Al as a medical isotopic tracer, particularly in the investigation of neurodegenerative diseases (^{26}Al and ^{10}Be analysis would also be of interest to some earth scientists), and the analysis of low level impurities in semiconductor materials. To develop the techniques for these analyses at IsoTrace would require some new equipment and research into AMS: a higher caesium current ion source in the case of ^{26}Al and magnetic analysis of the primary ion source beam in the case of semiconductor materials. Both would require only moderate expenditure and so are viable options for the near future. However, all new ventures require research and development funding which cannot entirely come from income from analytical services.

One other isotope of interest to hydrologists, ^{36}Cl, cannot at present be easily analyzed with the IsoTrace

equipment. Since this capability exists at the Chalk River Laboratories of AECL, there are no plans for developing this service at IsoTrace, although some research is being carried out in related sample preparation techniques.

Another service which may emerge from research currently in progress, is the analysis of some actinide elements. Like the ^{129}I analysis, this may be of primary interest to those monitoring nuclear material during production, use and disposal.

d) *Current condition of the IsoTrace equipment*

The basic AMS equipment in the IsoTrace Laboratory (accelerator, ion source, injection line and ^{14}C analysis line) has been in almost continuous use for eight years and prior to this was used extensively, both at the manufacturer's and at IsoTrace for testing and technique development. Some of the peripheral components, inherited from other projects have had an even longer history of operation. In addition to routine maintenance, minor upgrades on this equipment have been carried out as time and funds permitted. Nevertheless, some parts of the basic equipment are showing signs of aging and, to avoid excessive downtime, will need to be replaced within several years. In other areas, components are obsolete, in the sense that new components are now available which allow more efficient operation and considerably faster throughput of samples.

Some of the existing equipment, for example components on the heavy element line, is technologically up to date and is being used as the basis for the development of further analytical techniques. Developments which are currently in progress include the building of a higher capacity, more versatile ion source with lower maintenance time requirements and the installation of the OSIRIS high resolution injection magnet to provide a second injection line for the accelerator.

e) *AMS Research at IsoTrace*

IsoTrace personnel began research into what later became AMS, in 1976 by searching for an accelerator with a suitable sputter ion source to demonstrate that as a result of the instability of N^-, ^{14}C could be detected at natural abundances with low memory effect. Since then much of our research and development was carried out first of all at the University of Rochester and later at the IsoTrace laboratory. As a group of nuclear physicists we initially tended to emphasize the physics of AMS. However, after geologist John Rucklidge joined the group in 1979 and with the support of Ursula Franklin and the Collegium Archaeometricum, research into the applications of AMS began.

Research into AMS is necessary because of the need to understand the many unfamiliar phenomena encountered and to develop new equipment required to measure them. Further work is then needed to improve the quality of the new analytical measurements made possible by this research. Some areas of AMS research which have been undertaken by

IsoTrace laboratory personnel are as follows:

Isobar Separation. At Rochester we were able to demonstrate, in collaboration with Prof H.E. Gove, Dr K.H. Purser and others that negative ions could be used to facilitate low level measurements of ^{14}C, ^{26}Al, ^{36}Cl and ^{129}I. The first Ph.D. for AMS research was awarded to L. R. Kilius. Now at IsoTrace similar studies are extending the range of knowledge of isobar separation by negative ion methods. For example SH^- stability and ClH^- instability can be used to study ^{33}S. Likewise, Fe^- stability and Mn^- instability can be used to study ^{53}Fe. In addition to negative ion methods, BeO^{++} stability and LiO^{++} instability can be used to separate ^7Be and ^7Li. Many other pairs are being investigated.

Molecular Destruction. In addition to the separation of isobars the destruction of molecular interferences is essential to the success of AMS. The Rochester group discovered the stability (metastability) of CH_2^{++}. Later we showed at IsoTrace how this problem could be overcome and H.W. Lee, a graduate student, made the first radiocarbon measurements using doubly charged atoms (PhD thesis, 1988). Studies of other doubly charged molecules were also carried out by graduate students. More recently, as reported at this workshop by Dr. M. Anthony, the long lived triply charged molecule B_3^{+++} has been found.

The Spectroscopic Properties of Negative Ions and Multiply Charged Molecules. Because of their importance to AMS such studies are well worth while and they indicate the value of placing an AMS facility in a physics department. As an example, Yb^-, which is a very difficult ion to study, was predicted to be stable by Prof S. Vosko and collaborators of the physics department and recently a pair of letters on the subject was accepted for publication. Detailed surveys of the negative ions of all the elements are being made by IsoTrace graduate students (Nadeau, Garwan and Zhao) and recently the ions Gd^-, Yb^-, Hf^-, Th^- and U^- have been observed. A by-product of this work has been the observation that ^{230}Th and ^{231}Pa can be detected at natural levels in uranium ore (Zhao). One of the graduate students (Nadeau) has built apparatus for dissociating certain types of negative ions.

Ion Sources. Studies have been made of Cs^+ ion source properties and strategies devised for getting around some of their limitations. The insertion of an electric analyzer after the ion source has been found to be of great help and is being widely copied.

A graduate student (Aardsma) constructed an I^- sputter source and used it to produce Al^+ ions from alumina. These ions were then charge changed to Al^- and ^{26}Al observed at a ratio to ^{27}Al of 10^{-12} using doubly charged ions. This successful but primitive equipment has not been developed further because of a shortage of funds and personnel.

A new Cs^+ ion source, based upon the

present design but more flexible in the variety of uses and with at least a 60 ^{14}C sample capability, will be installed later this year. It was designed by Drs Kilius and Kieser and will have a milliprobe (down to 50μm) capability.

Ion Optics. Specialized devices are needed for AMS. Two such devices, the Recombinator [2] and the Isochronator, have been designed and patented. A Recombinator has been built by the US-AMS Corporation and tested for the new Woods Hole Radiocarbon Facility. It allows all three carbon isotopes ^{12}C, ^{13}C and ^{14}C to be injected simultaneously into a tandem. The all-electric Isochronator is for high resolution broad band mass measurements by time of flight.

Heavy Ion Detectors. Work is continuing on ionization detectors and the most recent version has given a resolution of 1.8% for 10 MeV I^{+5} ions. Thin polypropylene windows have been made by a graduate student (Zhao).

Trace Element Analysis. An ongoing programme at IsoTrace has focused on the analysis of precious metals (Au, Ag and the six platinum group elements [PGE] Os, Ir, Ru, Rh, Pt and Pd) in sulphide and oxide minerals, graphite and metals [3-5]. It provides an example of applied research in Canada using AMS for enhanced secondary ion mass spectrometry (SIMS). So far the prime applications have been in economic geology, but trial studies have also been initiated in archaeometry and meteorite research. The value of measurements of this kind is not limited to PGE, some of which are much harder to detect than many other metals. Similar trace element projects are clearly feasible in a broader spectrum of materials science, throughout the periodic table.

Radiocarbon Background studies. Dr R.P. Beukens has been studying the limits of radiocarbon dating both in connection with accuracy and age limit. This has led to work relevant to 1000 tonne liquid scintillator detectors for solar neutrino studies. Natural gas enriched in ^{13}C and also in ^{14}C has been studied and the level of $^{14}C/^{12}C$ in the original methane shown to be $< 10^{-18}$. Consequently, ^{14}C radioactivity will not be the limiting factor in the construction of a large neutrino detectors, although the materials of construction will have to be carefully studied at all stages. This kind of research illustrates well how research and development at IsoTrace can have significant implications beyond AMS. An NSERC Subatomic Physics committee once reduced the operating grant of A.E. Litherland because it didn't think that subatomic physics funds should be used to support radiocarbon dating. Fortunately that reduction was restored.

As a result of the research and development the equipment at IsoTrace has been upgraded significantly since it was received. Details can be found in our Annual Reports.

Criteria for Future Planning

a) *Flexibility and maintenance of service*

We anticipate that the demand for AMS services will increase steadily, although it is difficult to predict the strength of the demand in specific areas. Nevertheless, it is important to avoid any long term shut-down of existing facilities; at other facilities such events have created backlogs of monstrous proportions. We also expect the development of AMS techniques and equipment to continue for some time, so future plans for equipment must be flexible and involve, for example, anticipating the need for additional space around the centrally located accelerator, especially for connecting new ion sources and new high energy analysis systems. In addition, the level of automation of the spectrometer must be increased for heavy element operation so that the number of applications which can be run on a 24 hour per day basis can be increased and so that the reproducibility of equipment settings and thus the overall quality of the data can be improved.

b) *Economic considerations*

A laboratory such as IsoTrace, which presently relies on analytical income for over two thirds of the funds necessary for operation must perforce be as efficient as possible in the use of both equipment and staff. It must maintain its user base by steady improvement of existing analytical techniques and in the event of shifting analytical requirements within the user community, it must be flexible in introducing new areas of analytical services. Both these aims are best accomplished by continuing a vigorous program of research and development, *but this must also be funded.*

Considering the age of the basic equipment, even the maintenance of the current level of service will require the expenditure of some capital. Additional services, or the expansion of existing services will necessitate entering into competition with other worthwhile scientific endeavours for the funds available in Canada for research. The establishment of a new facility in some other location will require not only considerable funding but also scientific (and academic, if the facility is situated at a University) leadership and technical expertise which is not yet widely available within the small AMS world community. Funding at any level will not become available unless a significant fraction of the user community strongly requests it. Indeed, the prioritization of the various options for future development listed in the technical appendix should itself come from the user community, before any funding can be sought.

c) *The role of the AMS Workshop*

Most AMS laboratories essentially operate by providing services for other researchers. The fluctuations of individual research interests, institutional research priorities and national research goals makes prediction of the demand for AMS services extremely difficult. This is compounded in the case of AMS by the

general lack of easily accessible information about the capabilities of the technique. Advances in technique tend to be published in journals which are not familiar to the majority of AMS users. The technical difficulties encountered by the operators of AMS facilities may appear to be arcane or incomprehensible to the average user but these can directly affect the quality of the data received.

Those attending the workshop will already have a basic awareness of the capabilities of AMS. The first morning is devoted to providing a global view, not only of the general state of advancement of techniques, but of the scale on which these are used in various research disciplines and in various parts of the world. Against the background of this information, in working groups composed of those interested in applications in a single discipline, the participants will be asked to assess the need for AMS services to that discipline in Canada. When the reports from these working groups are brought together, it is hoped that some degree of prioritization can take place and that perhaps some suggestions for funding these priorities will arise.

An additional problem for the workshop to address is the method for funding research into the fundamentals of AMS and the development of AMS techniques. NSERC has not been able to resolve this problem and so advice is needed. For example, the research of A. E. Litherland into AMS was first funded from the Nuclear Physics Grant Selection Committee (GSC), then the Subatomic Physics GSC, then the Earth Sciences GSC and now the Interdisciplinary GSC. As might have been expected, these changes have not worked to the advantage of the research which needs to encompass such diverse topics as ion optics, ion sources, atomic physics and nuclear physics. Fortunately, equipment grants from the Strategic Grant Program have rescued some of the research, so perhaps research into and development of AMS should be formally included in the Strategic Grant program, because of its relevance to the strategic areas of biotechnology, energy, mineral resources, oceans and inland waters and environmental quality. The opinions of the participants in the workshop would be of value.

The areas covered above, in the section on Current Status, are only those which have reached our perception at IsoTrace. We expect that requests for new services, or new levels of older services may arise during the course of the Workshop. We ask those who have expressed interest in the Workshop, before coming, to reflect, especially with their colleagues, on what their needs will be. Those who cannot come to the Workshop are asked to send us these reflections on paper so that they can also be considered by the working groups.

Technical Appendix - AMS Equipment Options

As indicated above, the maintenance of existing programs and the development of new ones all require some investment in new equipment. While many upgrades can be carried out piece-meal, quite often there is considerable cost effectiveness (especially when operating costs are included) in replacing assemblies of components rather than one or two sub-assemblies. The reader is not expected to absorb the contents of this section in detail; rather, it is presented as a technical appendix, which can give the user an idea of the scale of changes (and capital funding) required for various future options.

a) *The tandem accelerator*

The most fundamental change which could be considered is the replacement of the present tandem accelerator with one of more modern design. Instead of the replacement of the existing accelerator tubes and 3 MV power supply required within three years, this may be a preferable alternative. This section also serves to describe the accelerator which would have to be purchased for any new facility and to point out the extent to which the current IsoTrace machine has become obsolete. In the event that a second spectrometer system is needed, there are advantages in locating it at IsoTrace, to take advantage of the existing technical and administrative infrastructure. Space near the present spectrometer is available, so services such as SF_6 handling could be shared. In such a scenario, the new spectrometer would probably be dedicated to ^{14}C analysis, and the older machine, upgraded at a slower pace, would be used for heavy elements, research and development.

The following description of the current AMS accelerator technology is based on the accelerator recently installed at Woods Hole Oceanographic Institution. It provides the following improvements over the existing one at IsoTrace:

1. Larger diameter, electrically and magnetically suppressed acceleration tubes. These allow better vacuum pumping of the acceleration region and consequently higher ion beam currents and more stable voltage operation. The tubes on our present machine will ultimately require replacement as a result of normal aging. The high energy acceleration tube also includes a design, introduced by US-AMS Corporation, which suppresses ions that charge change during acceleration. This reduces the continuum of ions from which some of the background in AMS work is derived.

2. The elimination of a separate bridge structure to support the equipotential rings, terminal cladding, column resistors and other ancillary equipment. This insulating component has been thought to limit the voltage holding capability of the accelerator. These components are now supported directly on the bridge consisting of the accelerator tubes and terminal vacuum enclosure under compression from the ends of the pressure vessel. This improvement requires a stronger pressure

vessel for the tandem, but it increases the voltage holding ability for continuous operation to at least 2.5MV and for tube conditioning to 3MV. This higher voltage will improve the beam quality and the efficiency for the analysis of heavy elements. It will also improve the resolution of the ionization detector for the heavy elements which is important for rejecting background.

3. Removable equipotential rings. These rings (used to control the gradient of the electric field) are split horizontally so they can be removed for easier access to the tubes, the resistors and the terminal alternator drive shaft (required to operate the terminal turbo pump). This significantly reduces in-tank maintenance time.

4. Completely solid state high voltage power supply. The high power radio-frequency vacuum tube oscillator has been replaced by a more efficient, higher output solid state device. This will eliminate the twice or three times yearly replacement of the vacuum tubes, a major component cost of operating the accelerator. The high voltage rectifying stacks used in the new power supply have been shown to be considerably more rugged and so will reduce both replacement cost and maintenance time.

5. Improved ion injection optics. This system, based on an IsoTrace design accelerates the ions across two gaps outside the pressure vessel. The object for this initial acceleration is located at the first principal plane so that the object for the accelerator tube is then located at the second principal plane. Mass-energy defining slits can be located in the field free region of the first principal plane. This arrangement produces lower aberration acceleration of the ions to the correct energy and the correct ion object position for the low energy acceleration tube.

6. Larger diameter stripping canal. This improvement will reduce and probably eliminate transmission variations of the isotopes due to small variations in beam waist size and position in the stripping canal and reduce still further the small losses due to multiple scattering of the ions during charge changing. We are also considering the addition of either a second stage of magnetically levitated turbine pumping or cryopumping to reduce still further the gas flow down the acceleration tubes. This would improve further the higher transmission for negative heavy ions already enhanced by the use of the larger diameter acceleration tubes with their lower residual gas pressure. It would also reduce the X-ray flux from the low energy acceleration tubes during high current operation. The use of a cryopump in a terminal, which has been demonstrated by High Voltage Engineering Europa (HVEE) would mainly benefit the heavy element work. These important options need active research and development.

Approximate costs for the accelerator related items (in Canadian dollars) are:

Complete AMS system for ^{14}C analysis (including a recombinator - see section d)	$2,000,000

Accelerator, including 3MV power supply	$1,000,000
3MV power supply upgrade to existing system	$500,000
Accelerator tube replacement	$100,000

b) The Ion Sources

At present, the ion source supplied in the original equipment order, with the early IsoTrace modifications to the sample stage required for automated operation, is still being used. Designed originally for 25 mm diameter geological sample mounts, its adaptation and operation for radiocarbon analysis has been very successful, having demonstrated the highest accuracy of any AMS laboratory[1]. Targets can be repeatedly and rapidly analyzed using a variety of strategies depending on the amount of material available for measurement. However the sample stage capacity is limited to 7 targets, usually 5 samples and two standards, and, by contemporary standards, this causes rather inefficient use of the system resulting from the lengthy two hour changeover to a new set of targets. While higher capacity sputter ion sources are now being marketed, the geometry of the primary caesium beam is probably unsuitable for high precision ^{14}C analysis and for low contamination analysis of geological and semiconductor samples.

Consequently we have been designing an ion source system which incorporates the ideas accumulated with the past eight years' experience and which allows further developments in the future. Through an agreement with High Voltage Engineering Europa B.V. we will receive the prototype of this source for testing in December 1991. By April 1992, we expect that this source will become the production source for the IsoTrace system. The basic design principles are:

1. Better ion source pumping for more rapid target and ion source component changes as well as higher analysis quality.

2. Capacity for a larger number of targets. The new design can accommodate up to 60 radiocarbon targets or a larger number of geological or research samples.

3. Space for two caesium guns (primary beam ion sources) for: (i) higher current operation, (ii) operation while one gun is being serviced, or (iii) the capability to alternate between radiocarbon and geological milliprobe analyses without an extended ion source shut down.

4. Gate valves to isolate the major components of the system so that components can be replaced or cleaned without breaking the vacuum in the caesium guns and so that a caesium gun can be removed for service while the source is in operation.

5. More convenient and better quality Cs^+ and C^- focusing and steering, and Faraday cups in the primary column to stop the beam when required.

6. A modified hemispherical extraction geometry to reduce the wedging of the electric field near the sample.

We also intend to continue to investigate positive ion sources with charge changing to negative ions and thermal ionization sources for particular applications. If a high current source (HVEE 846) is required for ^{26}Al work, the current cost is about $100,000.

c) Energy Analysis and Ion Beam Switching

The negative ion beam from the source is passed through a 45° spherical electric analyzer to select ions of the proper energy. Currently, this device can be rotated to allow switching between two ion source positions but this presents some difficulties in alignment. An improved design is now available with a port at 0° (primarily for alignment purposes). This will give us the opportunity of testing new ion sources without significantly interrupting analytical or research work or quickly alternating between two different types of ion sources. This component could be built in local workshops for a cost of about $50,000.

d) The Mass Analysis System

There are obvious advantages to analyzing all isotopes of interest simultaneously and so a system for doing this for radiocarbon has (masses 12, 13 and 14) been designed and patented[2]. A version of this system has been built and tested at US-AMS Corp., is currently being tested at Woods Hole, and would cost about $100,000 to purchase. However, for other isotopic analyses the currently used sequential switching method has advantages, for example, ^{129}I which requires as much reduction of the ^{127}I ions as possible before injection into the tandem because of the much higher mass resolution needed to eliminate the accelerated ^{127}I ions. Consequently, both systems are being actively considered for the future AMS system at IsoTrace.

e) The Accelerator Injection System

There are advantages in locating an additional rotatable electric analyzer prior to the tandem accelerator. In this way, one not only multiplies by three the number of injection ports selectable without breaking vacuum as described above, but primarily enables the rejection of unwanted beams from molecular fragmentation. For example $^{14}NH^-$ ions from $^{14}NH_2^- \rightarrow {}^{14}NH^- + H$ will be magnetically analyzed as a mass 14 beam but easily rejected by an electric analyzer as the NH^- ions have the wrong energy. Similarly $MH_2^1 \rightarrow MH^-$ rejection is even more important if M is a heavy element with mass *M*. Then it can be shown that one needs, prior to tandem injection, either a magnetic analyzer with resolution $M/\Delta M \approx M^2$ or more simply an electric analyzer of resolution $E/\Delta E \approx M$ to reject such ions. After tandem acceleration a resolution of $(M + 1)(q + 1)$, where q is the positive ion charge, is needed for either the magnetic or electric analyzers to reject such ions. As in section c, the electric analyzer could be built for about fifty thousand dollars.

f) The Post Accelerator Analysis System

The present radiocarbon analysis line could be upgraded to improve the rejection

of the ^{12}C and ^{13}C ions interfering with the ^{14}C measurements beyond 50,000 years BP, and to improve the measurements of the ^{12}C and ^{13}C ion currents. The principal device required for this would be an electric analyzer or a velocity filter located between the two magnets on the ^{14}C line. The cheaper of these alternatives, an electric analyzer, would cost about $60,000.

g) Automation

The data acquisition and control computer on the ^{14}C line is requiring an increasing amount of maintenance time and should be replaced soon, as replacement components are becoming unavailable. This could be done for about $8,000.

h) Benefits

It is beyond the scope of this document to list the improvement in analytical capacity for all combinations of the above equipment options. By way of example, let us consider one scenario: the replacement of the accelerator, the installation of a recombinator and the inclusion of the high capacity ion source currently under development. This would provide for a least a doubling of the current ^{14}C capacity to ~ 1000 samples per year with higher precision ($\leq \pm 0.3\%$) and probably provide a similar increase in productivity for the other analyses. For ^{14}C this should have the effect of reducing prices to about 75% of the current level for normal precision measurements and reducing the turnaround time to an average of eight weeks, with seasonal maxima not exceeding 12 weeks. This would ensure state-of-the-art analytical measurements to at least the year 2000 at IsoTrace.

References

1. High precision intercomparison at IsoTrace. **R. P. Beukens**. Radiocarbon 32 (1990) pp 335-339.

2. A recombinator for radiocarbon accelerator mass spectrometry. **L. R. Kilius & A. E. Litherland**. Nucl. Instr. & Methods, B52 (1990) pp 375-377.

3. Sulfide gold content of skarn mineralization as Rossland, British Columbia. **G.C. Wilson, J.C. Rucklidge & L.R. Kilius**, Economic Geology 85 (1990) 1252-1259.

4. Geochemistry land mineralogy of the Late Archaean Owl Creek shear-hosted gold deposit, Timmins, Ontario, Canada. **G.C. Wilson & J.C. Rucklidge**, Extended abstract volume, Third International Archaean Symposium, Perth (1990) 391-393.

5. In situ analysis of precious metals in polished mineral samples and sulphide "standards by accelerator mass spectrometry at concentrations of part-per-billion. **G.C. Wilson, L.R. Kilius & J.C. Rucklidge**, Geochimica et Cosmochimica Acta 55 (8) (1991).

Some Recent Canadian AMS Publications

The proceedings of the 5th International Conference on Accelerator Mass Spectrometry were published recently in Nuclear Instruments & Methods Vol. B52 Nos. 3 & 4 (1990). The following papers had at least one Canadian author and so represent Canadian contributions to AMS.

1. Development of the Chalk River program for ^{36}Cl. **H. R. Andrews** et al, pp. 243-248.

2. Operation, Analytical work and research at the IsoTrace Laboratory. **W.E. Kieser**. pp. 249-253.

3. AMS of heavy ions with small accelerators *(Invited paper)*. **L.R. Kilius** et al, pp. 357-365.

4. Injection systems for AMS: Simultaneous versus sequential. **J.R. Southon** et al, pp. 370-374.

5. A recombinator for radiocarbon accelerator mass spectrometry. **L.R. Kilius & A.E. Litherland** pp. 375-377.

6. Electric dissociation of negative ions. **M-J. Nadeau & A.E. Litherland**, pp. 387-390.

7. A new method for the separation of the isobars ^{7}Be-^{7}Li. **X-L. Zhao** et al, pp. 416-420.

8. The elimination of charge-changing backgrounds in an AMS radiocarbon system. **K.H. Purser & A.E. Litherland**, pp. 424-427.

9. In situ trace element determination by AMS. **J.C. Rucklidge** et al, pp. 507-511.

10. The negative ions of strontium and barium. **M.A. Garwan** *et al*, pp. 512-516.

11. Accelerator mass spectrometry in the biomedical sciences: applications in low-exposure biomedical and environmental dosimetry *(Invited paper)*. **J.S. Felton** et al, pp. 517-523.

12. Application of AMS to biomedical sciences. **J.S. Vogel**, pp. 524-530.

13. Application of AMS in aluminum metabolism studies. **O. Meirav** et al, pp. 536-539.

Fig. 1 Usage of IsoTrace (hours)
1990 calendar year

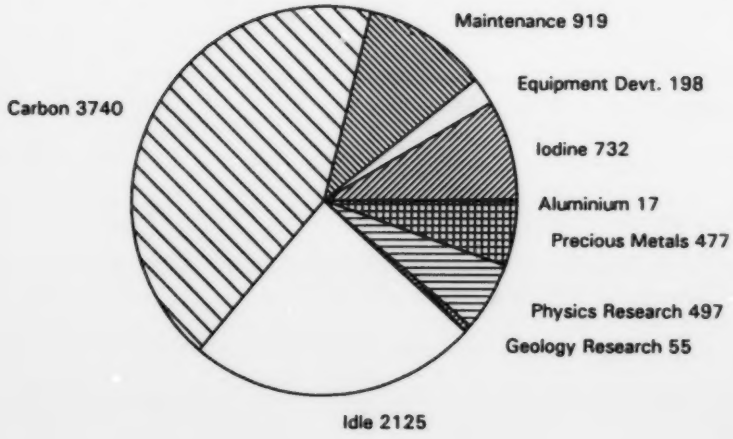
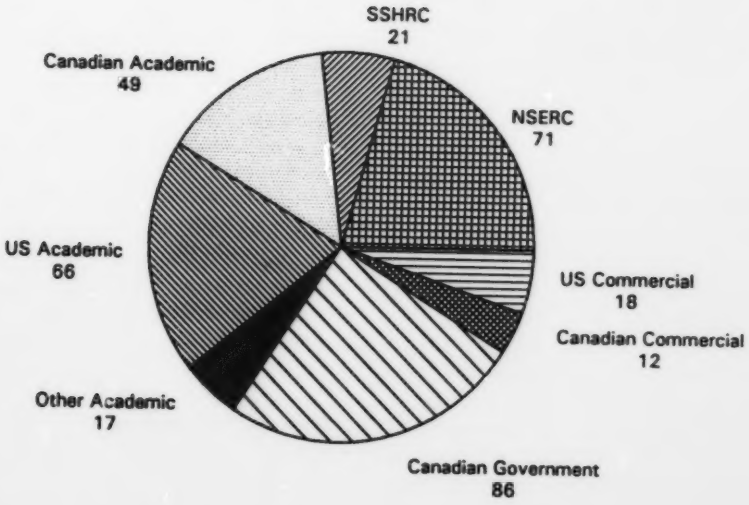


Fig. 2 Users of IsoTrace
Number of Carbon Samples



The Alberta AMS Project

S. T. Lam

Nuclear Research Centre
University of Alberta Edmonton, Alberta Canada T6G 2N5

Course of Project Development

The AMS project in Alberta was started in the fall of 1987 as a result of a suggestion from IsoTrace that a new facility would be needed in Canada to meet the expansion of AMS requirement over the next decade. A meeting of people in the Edmonton area who were interested in the project was held and tremendous enthusiasm was shown at the meeting to explore the idea of setting up an AMS facility. A project committee was formed consisting of scientists from the University of Alberta, the University of Calgary, the Alberta Environmental Centre and the Archaeological Survey of Alberta.

The Alberta Research Council soon got interested in the project. On November 7, 1988, the University of Alberta and the Alberta Research Council hosted a regional one-day workshop to inform users and potential users of AMS about the project and to explore the capability of and future demand on AMS. Dr A.E. Litherland (IsoTrace) served as a facilitator, providing perspectives on the establishment of an AMS facility and considerations of possible future requirements. Apart from university and government laboratory researchers, there were also representatives from the ministry of Alberta Technology, Research and Telecommunications (TRT) and the business sector attending. A panel discussion was held at the end of the workshop. Both scientific and financial issues were discussed. The scientific community welcomed such a new device, as it would complement the existing conventional ^{14}C counting facility at the Alberta Environmental Centre. The researchers felt the availability of AMS and beta-scintillation counting would expand the horizons of their research fields. The position of Alberta TRT was that the facility should have an industrial component, if funding is to be sought from the ministry, as its mandate is to enhance the economic growth of the province through application of technology. A recommendation was

made by the panel and participants that a feasibility study be carried out to explore these two aspects.

As a result of a series of discussions between the AMS Project Committee, the Office of Vice-President (Research) of the University of Alberta, the Office of Vice-President (Development and Planning) of the Alberta Research Council and the Ministry of Alberta TRT, it was decided that a business plan be prepared and financial support for the preparation be provided by the above three organizations. The business plan was completed in May 1990. The executive summary of the business plan is attached as an appendix in this report.

The AMS Project Committee also informed NSERC of the Alberta project. The reply from NSERC was that NSERC would respond to the project after examining the outcome of the present workshop on AMS. This is also the attitude taken by Alberta TRT.

The Proposed AMS Facility

The proposed AMS facility would consist of a negative ion sputter source, a mass recombinator, a 3 MV high-current Tandetron accelerator, a high energy mass spectrometer and a computer control for operation and data acquisition. This system is similar to the one at Woods Hole Oceanographic Institute and can be purchased from HVEE Amerfoort. The system can measure more than 3,000 graphite targets per year with an isotopic-ratio precision of better than 0.5%.

Alberta Support

The following is a list of people from Alberta supporting the AMS project.

Alberta Research Council

Dr Duncan Currie, Vice,-President (Development and Planning)
Dr Jan Boon, Director (Development and Planning)

Alberta Geological Survey:
Dr Rick Richardson

University of Alberta

Dr Bob James, Vice-President (Research)

Department of Anthropology:
Dr Alan Bryan
Dr Ruth Gruhn
Dr Mary Jackes
Dr Raymond Leblanc
Dr Nancy Lovell
Dr David Lubell*
Dr Charles Schweger*
Dr Pamela Willoughby

Department of Botany:
Dr Michael Hickman
Dr Dale Vitt*

Department of Classics:
Dr Maurizio Gualtieri

Department of Forest Science:
Dr Victor J. Lieffers
Dr S. Ellen MacDonald
Dr Ross W. Wein

Department of Geography:
Dr Ian Campbell
Dr John England*
Dr Bruce Rains

Department of Geology:
Dr Nat Rutter*
Department of Soil Science:
Dr Bill McGill

Faculty Of Pharmacy and Pharmaceutical Sciences:
Dr Len Wiebe

Department of Zoology and Environmental Research and Studies Centre:
Dr Ellie Prepas

Nuclear Research Centre:
Dr Tsing Lam*
Dr Croy Neilson*

University of Calgary

Department of Archaeology,
Dr Nicholas David, Head

Department of Geography:
Dr Gerald Smith

Department of Geology and Geophysics:
Dr Gerald Osborn

Department of Physics:
Dr Roy Krouse*

University of Lethbridge

Dr Robert J. Pogmon
Department of Geography

Government Institutions

Alberta Environmental Centre, Vegreville, Alberta:
Dr David Arnold*

Archaeological Survey of Alberta, Edmonton, Alberta:
Dr Alwynne Beaudoin*

Provincial Museum, Edmonton, Alberta:
Dr James Burns

Canadian Forestry Service, Edmonton, Alberta:
Mr. Steve Zoltai

Geological Survey of Canada, Calgary, Terrain Science Division:
Dr Alejandra Duk-Rodkin
Dr Owen Hughes
Dr Ruddy Klassen
Dr Don Lemmen

* member of AMS Project Committee

Appendix

Executive Summary from the Business Plan for the Proposed Accelerator Mass Spectrometry Facility in Alberta (May 1990)

A consortium of Alberta researchers proposes to install an accelerator mass spectrometry (AMS) facility in Alberta. This high technology facility, which is an ultra-sensitive mass measuring device, would significantly enhance the capability of many Alberta researchers who are in the forefront of many fields. The facility would also be needed by the emerging international environmental programs on Global Change. Because of the potential markets in industries and medical applications, such a facility can be viable as a business proposition.

This is a unique opportunity for Alberta to culture its hi-tech industry by installing a world-class facility. The universities in Alberta have the most diverse group of interdisciplinary scientists in Canada concerned with environmental change. There is also the long existing accelerator expertise at the University of Alberta. The proposed facility would provide radiocarbon measurements to the scientific and industrial communities. Apart from the business aspect, the facility would enable the re-investment of considerable federal research grants within the province. This business plan, jointly funded by the University of Alberta, the Alberta Research Council and Alberta Technology, Research and Telecommunications, was prepared as a result of a feasibility study on the proposed AMS project. Highlights of the business plan are:

AMS is a new technology. This is an opportune time to enter the field, since the technology is established and the market competition is still minimal. AMS has been increasing its market share among the existing users of radiocarbon. The market for radiocarbon analysis is also increasing because of the urgency in collecting proxy data for environmental modelling. With the implementation of Global Change programs, both Canadian and foreign, the proposed AMS facility will be certain to attain its market projections.

The industrial market for the proposed facility will come from agriculture, forestry and oil. However, this market has to be developed, since most industrial R&D departments are unaware of the AMS technology.

Capital equipment costs for the proposed AMS facility are about $3.1 million, which includes an AMS system and a building to house the system. It would take twenty-two months from the day the purchase order is placed with the manufacturer (US-AMS Corporation) to complete the facility.

Annual working capitals of $200,000, $270,000 and $110,000 would be required respectively for the first three years of operation. The break-even point (i.e., revenue equals expenditure) would be reached around the beginning of year-4.

In a business modelling of the proposed facility, a 15-year time period is used to demonstrate its viability. The facility and its improvements are assumed to depreciate 10% per year. Upgrading will be carried out to maintain it as a world-class facility. Investment principal will be repaid to the owners of the facility starting from year 6 and completing by year 15. The financial benefits to the owners at year 15 would be a cash asset of about $5 million plus the ownership of a world-class facility, able to generate an annual revenue of $1.8 million.

The impact of the proposed facility to the regional economy is considerable for an investment of only $3.7 million. The total operating cost of the facility is expected to amount to about $15.2 million over the 15-year period. Using an economic multiplier of 1.5, this means the facility would inject into the regional economy an average of about $1.5 million per year, in the form of employment, goods and services.

Cost estimates in this report do not include overhead, which will be assessed by the host institution.

It is recommended that the Alberta Government and the Federal Government be approached for the capital funding of the proposed facility. As the facility progresses toward a mature stage, transferring it to the private sector should be considered.

If the capital comes from the governments as a grant and no pay-back of the Capital is required, then the profit made by the facility should be used to reduce analysis fees. In this way the benefits would be passed on to the scientific community.

Market development is essential to the financial success of the proposed facility.

The critical risk for the proposed facility is that the future AMS market is smaller than expected and hence the facility cannot attain its projected share. This situation may occur if the Global Change programs are not implemented. However, because of public concern about the effect of environmental change, it is unlikely the governments in the world will abandon environmental studies, especially when President Bush of the USA has committed $1 billion to the cause. Even in acute economic situations, environmental

programs will more likely be down-sized than abandoned entirely.

Support from the traditional studies in earth and life sciences is the bread and butter for the proposed facility. With this support as a stepping stone, market development in industrial sectors can be started. If the industrial market turns out to be large, then the goal for the proposed facility to attain its financial projections can still be reached, even without the full implementation of Global Change programs. If the market turns out to be small for both Global Change and industry, then the, proposed facility would evolve into a self-supporting, first-class world facility serving the basic needs of the scientific community.

On the establishment of an AMS Facility at the University of Alberta[1]

J. England

Department of Geography

D. Lubell & C. Schweger

Department of Anthropology
University of Alberta, Edmonton, Alberta

A diverse and established commitment to palaeoenvironmental research at the University of Alberta makes it a logical site for the expansion in AMS facilities in Canada. The interest in developing AMS technology for radiocarbon dating extends back for more than a decade at the University whose researchers, subsequently, have been active users of IsoTrace Laboratory, University of Toronto. Given the prospects of expanding this technology in Canada to meet the growing national and international interest in environmental research, an AMS Committee was set up at the University of Alberta in 1988.

Considerable groundwork has been completed regarding the spectrum of interest in western Canada, especially within Alberta universities, research institutions of the Provincial Government and the private sector. It is clear that any such facility would include interested parties from adjacent provinces as well, and efforts have been made to contact their universities. An AMS laboratory in western Canada would also be as coordinated as possible with IsoTrace emphasizing a national agenda rather than two competing facilities.

The present meeting on the future of

[1] This paper was not given as an oral presentation at the workshop but was circulated in manuscript form.

AMS research provides an important extension to the workshop held at the University of Alberta in 1989 concerning the university's interests to pursue an AMS project. Subsequently the AMS Committee at the University of Alberta has prepared a Business Plan sponsored by both the university and agencies of the Provincial Government. This report reflects the enthusiasm for, and appropriateness of such a project.

The development of an AMS facility at the University of Alberta would provide an appropriate and complimentary diversification of research in western Canada. Such a facility would be readily integrated into the ongoing research of numerous environmental projects (geochronology, archaeology, palaeoenvironmental research, and the analysis of human skeletal remains for isotopic and palaeodiet studies). In order to contribute significantly to international environmental research, in which Canada has established a strong reputation, we must also be involved, first hand, in appropriate analytical techniques. An AMS facility in western Canada would be a creative and well-utilized resource. It would also serve a growing national and international clientele pursuing issues such as Global Change.

Accelerator Mass Spectrometry Studies at UBC and Triumf

M. Johnson, E. Vengel and L. Gelbart

Department of Physics
University of British Columbia
Vancouver, BC V5T 1W5

Summary

This report describes the use of Accelerator Mass Spectrometry for tracer work in medical applications. The use of ^{26}Al and ^{41}Ca are important in studying the kinetics of these elements in clinical medicine. Sample preparation is one of the major bottle-necks in the process of AMS analysis and the projects we have done has resulted in a facility for tracer work that has the injected bolus preparation at one site while the sample preparation is at another. The full study is a collaboration with existing AMS facilities and medical researchers with each participant bringing the appropriate expertise into the programme.

Samples and collaborations: an Introduction

A very costly and demanding component of AMS analysis is the sample preparation facility. The environmental and clinical medicine work that we are involved in generates a large number of samples, which poses a problem for most AMS laboratories in that such large numbers of samples monopolize extant preparation facilities as well as burden the accelerator time when manual operation of the facility is used. Moreover, the actual techniques of sample preparation for biological samples are just beginning with procedures unique to each material being established. We have established AMS sample preparation techniques for biological samples which allow us to provide analysis-ready samples that are compatible with AMS. Exceptional control of low level activity is required, with facilities for specific radioisotopes being isolated and controlled.

The overall thrust of the UBC programme is to enable preparation of

hundreds of samples per year for AMS analysis. Initial procedures used for the extraction of the various elements from the original sample and the preparation of a sample suitable for AMS measurement are documented (see for example the Proceedings of the Fourth International Symposium on AMS, NIM B29 1987) and involve standard chemical methods. Still, these procedures have to be done very accurately and carefully to ensure that the final product is adequate for AMS analysis in a way unique to each biological sample. The samples must also be prepared in such a way as not to be cross contaminated, nor may they contaminate the laboratory. Our tracer work in Al and Ca must be separated with the input boluses prepared in a laboratory quite distinct from the tracer samples themselves whose rare isotope content is on the same scale as possible geological samples.

Our AMS collaborators are:

Middleton et al., University of Pennsylvania (^{26}Al); see publications.

Paul et al., Jerusalem University (^{26}Al, ^{41}Ca, ^{129}I); main medical applications collaborators.

Our UBC collaboration is:

R. Sutton, UBC & VGH; Al and kidney function.

V. Walker, UBC; Al and kidney function.

K. Schoenholzer, UBC and VGH; Al and kidney function.

J. Prior, UBC and VGH; Ca and Osteoporosis.

V. Sossi, UBC; Al and Ca Modelling.

E. Venczel, UBC/SFU; Sample Prep.

Z. Gelbart, TRIUMF; equipment development.

R. Johnson, UBC/TRIUMF; I and biomed applications.

We have occupied laboratory space in the UBC Physics department for the preparation of AMS samples. There is one isolated laboratory allocated for the preparation of ^{14}C Samples. This lab will produce CO_2 from biomedical samples resulting from doped ^{14}C pharmaceutical work. A second area has been assigned for the environmental ^{129}I work at natural levels and can be isolated. A third laboratory area well separated from these rooms is currently used for ^{26}Al tracer work in medical research related to kidney function. That area shall continue to be used for Al tracer work. An additional area is equipped for Ca tracer sample preparation. The medical tracer work requires preparing isotopes for administering to animals and patients. This input stage handles high levels (by

AMS standards) of activity and this step is done at TRIUMF with independent equipment. Maximal separation therefore exists.

Sample preparation for AMS is traditionally done at-home at each AMS laboratory. With close collaboration with our AMS collaborators, the overall throughput of samples required in this series of experiments may be accomplished.

The group is also involved in training students as well as R&D work in relation with AMS.

Research Programs

The research programs to be undertaken with this facility encompass several disciplines. This section provides only a brief description of the various projects. A detailed operating description for each of the projects is embodied in experimental proposals and ethics committee reviews and these proposals and reviews are available upon request.

General

The technique of Accelerator Mass Spectrometry (AMS) allows measurements of extremely small isotopic ratios (about 10^{-15}) and is most powerful in detecting very low concentrations of long-lived ($T_{1/2} \geq 10^3$ years) radioisotopes. AMS is capable of counting directly the number of atoms of radionuclides in the sample whereas with conventional techniques their decay products are detected. In the last decade AMS has been applied in many fields such as archaeology, geology, oceanography, hydrology and cosmochemistry, mainly for dating purposes. At the moment, more than 30 AMS labs all over the world are operational, most of them using old Tandem-Van de Graaff accelerators.

Possible applications of AMS in biomedical and environmental studies have been examined and found to be feasible. Collaboration of our group with MDs and AMS labs has been established. A chemistry lab has been set up and sample preparation methods have been tested. A feasibility study of the application of AMS in aluminium metabolism research has been completed successfully. For the future, the extension of the activity in biomedicine, radioactive pollution environmental survey, analysis of nuclear reactor waste, oceanographic studies and AMS R&D work are planned.

Past

Our first task has been to check the applicability of AMS to biomedical research, the idea being to introduce long-lived radioisotopes as tracers into

biological systems and monitor their level in various samples (e.g. blood, urine, tissues, bones) by AMS. The long lifetime (small specific activity) of these isotopes combined with the ability to detect extremely small amounts (about a million atoms) are making this method capable of the following:

studying long turn-over rates (e.g. bone deposition);

performing human studies (entailing radioactive doses of several orders of magnitude below natural background);

introducing amounts of radionuclides that are neither prohibitively costly nor disturb the system steady-state;

using relatively simple chemical processes (no need to hurry as isotopes practically do not decay and no need to take special radioactive precautions as activity involved is minimal).

When the usefulness of this new tool became clear, a group of MDs from the Vancouver General Hospital (VGH) was approached, leading to informal workshops. The outcome of these were proposals of joint studies of aluminium and calcium metabolism using as tracers ^{26}Al ($T_{1/2} = 7 \times 10^5$ years) and ^{41}Ca ($T_{1/2} = 1 \times 10^5$ years). It was agreed that VGH will be responsible for the isotope administration and sample collection and us for the sample processing and AMS measurements. Since AMS is a new technique in biomedicine, it was decided to perform a small scale experiment in rats to test the feasibility.

Aluminium has no isotope suitable as a tracer in kinetic studies other than ^{26}Al. Since the detection of this isotope is not practical by conventional methods, very little is known to date about the biological behaviour of aluminium in spite of the recognition of its potential toxicity. A test experiment was performed in which small amounts of ^{26}Al were injected into two rats followed by blood and urine collection over a three week period. The preparation of the "hot" material for injection was done at TRIUMF while the processing of the samples was carried out at a dedicated chemistry lab that we set up at UBC. The measurements were done at the AMS facility of the University of Pennsylvania. This test not only proved the feasibility of the technique but also provided new and valuable information about Al kinetics in rats. It was shown that over a few days. the ^{26}Al equilibrates with a pool amounting to about 5% of the total body aluminium, and about 76% is excreted in the urine. The residence time in the blood is about half a day and in the exchangeable pool about half a year. A summary of the work was published in the American Journal of Physiology and the technical details have been published in Nuclear Instruments and Methods.

Future

The main activity involves continuation and extension of the biomedical work and environmental studies. Several grant proposals have been submitted to support the operational costs of these projects (copies are available). A grant to support the ^{41}Ca work in rats has been awarded to J. Prior from the B.C. Health Care Research Foundation. Another grant for studying aluminium behaviour in healthy and renal failure rats has been awarded to R. Sutton from the Kidney Foundation. An interdisciplinary grant proposal for carrying out the iodine work has been submitted to NSERC.

Biomedicine

This work will include aluminium and calcium metabolism studies in animals and humans. We have considered tracer techniques using ^{14}C labelled pharmaceuticals as input material to study pharmaceutical long term behaviour in subjects.

Aluminium

Our first study using ^{26}Al has been extended to investigate body response to large loads of aluminium and gut-absorption of aluminium. These topics are of particular importance in the case of uraemic patients in whom aluminium metabolism is distorted leading to dementia, bone disease and anaemia. These studies involve a larger number of rats and includes intravenous as well as oral administration of the tracer. The animal experiments are expected to last 2 years and will involve about 100 samples/year. The UBC ethics committee has given approval to similar experiments with human subjects. In these later studies, the amount of ^{26}Al that has to be injected (about 30 pCi) will entail an internal dose to the subject of less than 0.1% of the natural background.

Calcium

A grant has been awarded to study the effects of several treatments on osteoporosis in rats. ^{41}Ca has been injected into the rats and at the end of the study the rats have been sacrificed and the concentration of the ^{41}Ca in bones will be measured. As in the aluminium case, this will be one of the first applications of AMS (see Elmore's Ca study) and a long-lived tracer to calcium metabolism study. In this case, the details of the short-term Ca kinetics are pretty well known (from ^{41}Ca studies in the past) and the importance of the present proposal is mainly in proving the feasibility of the method. It leads to similar experiments in humans. In fact, one of the VGH MDs already is serving as a subject in such an experiment accepted by the UBC ethics committee and is underway. About 100 ng of ^{41}Ca has been injected intravenously and blood and urine collections have been subsequently made. A bone biopsy has been performed and we will be given a small fraction (about 50 mg) of it for AMS analysis. Here too, the dose due to the radioisotope will represent only a

small fraction of the background (detailed dose calculation, based on the MIRDOSE computer code is available). For the calcium studies we expect 40 animal samples and 10 human samples.

Waste Management

Every nuclear reactor produces radioactive waste. Most of the activity is presented in the form of short-lived radioisotopes but when long-term handling of the waste is considered, only the long-lived ones become significant. The presence of the latter is very difficult to observe by conventional gamma counting whereas AMS is perfectly suitable for this task. We are collaborating with Ontario Hydro and are developing measurements of levels of long-lived isotopes (in particular ^{129}I) in the resins that filter the activity from the reactor cooling heavy-water system. These measurements are extremely important for them in order to know how to handle and control this waste. Preliminary measurements show that our detection limits suit very nicely the estimated concentrations. To do the chemistry on the relatively hot samples we can benefit from the experience and equipment of TRIUMF. Measurements of ^{129}I concentrations in groundwater around the disposal region are also being considered as they will reveal if and to what extent radioactive leakage exists.

R & D

The group will also be involved in research and development of AMS methodology such as ion sources, detection systems (filters) and control systems. Another interesting project that may lead to a dramatic reduction in the size (and hence the cost) of an AMS machine is Laser-AMS.

There are many problems at hand. The aluminium work is hindered by the availability of intense ion sources. We have begun to commission a new ion source for the Pelletron that would allow aluminium measurements there. In addition, plans for the collaboration to install a Wien Filter to enhance the sensitivity for calcium are underway. And finally a proposal for automating the Pelletron has been prepared and is under discussion.

All the current AMS machines use high voltages (2-14 MV) in order to achieve high sensitivities by discriminating against interferences (stable isotopes, stable isobars and stable molecules) during the radio-isotope measurement. This method works very nicely but it makes AMS an expensive tool. An alternative way to eliminate the above interferences is by combining a high intensity laser source into the AMS machine. By choosing the photon energy appropriately, high selectivity can be obtained via the processes of photo-detachment and photo-disassociation. A first test of this idea was done this year in Rehovot, Israel with very satisfactory results. Still, improvements of several orders of magnitude in the suppression and in the

duty factor are required before this method becomes applicable. It is possible that we will join an existing Jerusalem-ANL collaboration or do some R&D work of our own. One option would be to start with incorporating a laser into a conventional existing mass spectrometer (e.g. to discriminate against a background of ^{16}OH during measurements of $^{17}0$).

Such work can initially be done at an offsite partner in an AMS collaboration using their local resources. Perhaps those individuals can thus bring more equipment into solving the overall problem rather than exacerbating the problem by bringing unwelcome numbers of samples.

Research Personnel

The local team of researchers at UBC are comprised of Faculty, Post docs, and students, performing the roles of sampling, preparation and modelling as well as assisting in data taking. The students have opportunity to sample a wide knowledge and experience in both organic and inorganic methods. Such requirements are dictated by the large number of samples and the delicate nature of the work. It is expected that in addition to the routine sample preparation, the students are able to improve the existing procedures and to develop new ones as necessary (eg. to extract aluminium from tissues and bones).

Accessibility

The collaborators in this research are quite interdisciplinary and represent very diverse interests. They came together as a result of seminars and workshops held over the last year to define research topics that would benefit from AMS measurements. Each project undertaken in the laboratory is documented in a written proposal (eg. NSERC for oceanography, or the Kidney Foundation for the aluminium study) and hence peer reviewed. Any new project of a high scientific value will be welcomed.

Long term Objectives

The long term objective of the laboratory is to enable large quantities of samples to be processed by Accelerator Mass Spectrometry techniques. This opens the technique to processes that require statistical sampling and offers truly non-invasive tracer techniques in clinical medicine. The lab is engaged in ion

source development and beam separation technique development in order to enhance the throughput and sensitivity in the sample prep lab-AMS lab collaborations that have been established. In addition, the lab will propose other precision mass separation techniques and develop these to again enhance the opportunity for such techniques in disciplines such as oceanography, environmental studies, and clinical medicine.

VI. Reports from the Working Groups

1. Introduction

Seven working groups were established, covering the major areas of usage of AMS:

Group	Chair	
Earth Sciences	H. Schwarz	(McMaster University)
Oceanography and Marine Geology	G. Vilks	(Atlantic Geoscience Centre)
Archaeology	P. Julig	(Laurentian University)
Biomedical Science	D. Milton	(Chalk River Laboratories, AECL)
Hydrology	R. Andrews	(Chalk River Laboratories, AECL)
Materials Science	J. Brown	(University of Western Ontario)
Economic Geology	G. Wilson	(Turnstone Geological Services Ltd)

Non-Canadian participants were included in all these working groups as advisors.In addition the non-Canadians met later to draw up their own recommendations. All eight groups reported to the final plenary session and their conclusions were discussed in open conclave.

The terms of reference for the working groups are listed in appendix B.

2. Report of the Working Group on Earth Sciences

Chair: Prof. H. Schwarz, McMaster University

At present the cost of analysis keeps numbers down. Many more samples exist, but not the money to analyze them. If cost does not drop then some samples may never be analyzed. Perhaps a small number of free analyses should be available for the "needy" student projects, starters, etc.

The emphasis in dating should probably be upon older quaternary samples and some funding should be put into other methods, such as thermoluminescence. For the more recent dates (<20,000 years) AMS is the best method. Given the funds there would be call for 2,000 ^{14}C (high precision), 1,000 each of ^{10}Be and ^{26}Al, and 500 ^{36}Cl analyses per year. In addition, the global change program and a program on environmental air could generate many more analyses (these are not included in the summary table).

For field workers the turnaround time for most studies is the time between the close of one field season and the start of the next, with time to write up notes - 3 months (ideal) to 6 months. For graduate students shorter times are needed in order to complete theses. As the demand rises there will be need for a time allocation committee to determine priorities.

R&D is needed both in AMS techniques and in sample preparation techniques. An ultimate aim should be to perform ^{14}C dates on single pollen grains or on ice core gases.

Decentralization is important in sample preparation, not in actual AMS. AMS should not, however, be just one set of people analyzing the samples provided by another set (the users), but should be an integrated/interactive scientific venture. Even if external contract laboratories or individual researchers take over much of the labour-intensive work of sample pretreatment and preparation, the AMS laboratories must still be responsible for Quality Assurance/Quality Control and have their own resident wizards in this field.

^{14}C remains the bread and butter of AMS laboratories, but the total of other techniques may grow to match it. There is an immediate need for another machine for ^{14}C work, and a larger (higher voltage) accelerator is also needed for other isotopes. High user fees remain the major obstacle to greater usage of AMS.

Personnel: Start-up crews will come from accelerator physics, but final operating crews will embrace several disciplines.

Regional aspirations: AMS laboratories should be national (as in Australia). Quality of service is the only guide.

Summary of perceived annual needs in Earth Sciences

Isotope	Now	Five Years Hence
^{14}C (High Precision)	1,000	2,000
^{10}Be	100	1,000
^{26}Al		1,000
^{36}Cl	100	500
Actinides	100	100
Totals	1,300	4,600

3. Oceanography and Marine Geology Working Group Report

Chair: Dr. G. Vilks, Atlantic Geoscience Centre

AMS capacity in Canada should be expanded because:

Much of the ongoing research requires high resolution ^{14}C dating to determine chronologies of palaeoclimates and palaeoceanographic events. In the context of the Global Change Initiative, the growth and decay of the Laurentian Ice is monitored by $\delta^{18}O$ profiles in sediment cores, which need to be placed in an absolute time framework, especially in shelf waters that have been diluted by meltwater pulses, so that the established chronologies do not apply. The rigid chronological framework can only be obtained from high precision ^{14}C determinations.

Canadian participation in large international projects also places demands on readily available AMS dating facilities, such as ODP, radiocarbon assays on atmospheric methane, rate of carbon deposition in the oceans.

Turnaround time: 2-3 months

Continuing R&D into AMS itself is needed to develop techniques for smaller sample sizes and increased precision. An AMS facility should conduct high quality science to support chronologies for specific events, such as $\delta^{18}O$ and $\delta^{13}C$ profiles, which can be correlated between terrestrial and marine data. There will be high competition for use of AMS because for the foreseeable future, even if new machines are built, there will be insufficient capacity, both in Canada and world-wide. There is clearly a need for a dedicated ^{14}C machine and for increased efficiency through automation. Other isotopes, which require further extensive development, demand a dedicated AMS research team. Sample preparation can be done outside the AMS laboratory, so long as it is carried out in collaboration with an AMS team for QA/QC and development. Regional aspirations should be subjugated to open competition for funds to build new facilities. It is important to have facilities to train graduate students in AMS techniques. User fees are generally too high in Canada, compared with the subsidized fees charged in other countries, especially for young university researchers who need to do high resolution dating. The government has the basic responsibility for AMS establishment and support, but industry has a role too.

Additional comments were later received from Prof. Calvert of the University of British Columbia. They are printed in Appendix D.

Summary of perceived annual needs in Oceanography and Marine Geology

Isotope	Now	Five Years Hence
^{14}C (High Precision)	1,000	2,000
^{10}Be	100	100
^{32}Si		2,000
Actinides		100
Totals	1,100	4,200

4. Report of the Working Group on Archaeology

Chair: Prof. P. Julig, Laurentian University

We need to maximize use of present AMS facilities and manpower, but in addition there is need to expand. Demand in the near future is likely to be for about 200 high precision ^{14}C dates per year, in part to calibrate dates obtained by other methods and to date smaller samples. The turnaround time should be <4 months.

Collaborative research is vital, involving both archaeologists and the accelerator scientists. There is a need for cross-checking calibration against other methods (Thermoluminescence, U/Th, Electron Spin Resonance, dendrochronology, AAR, lichenometry, obsidian hydration, etc.). New materials must be explored and ways found of dating them, e.g. plasters, cements, metals. New isotopes could be developed for use - ^{41}Ca, for example.

Expansion would be best in existing facilities, where buildings and personnel are already to be found. Regional aspirations are best met by carrying out sample pretreatment and preparation locally, under central QA/QC. This will reduce costs to users and also utilize current radiometric laboratories, which may be gradually decommissioned.

Personnel: AMS requires experts in physics, chemistry, geology, archaeology, all working together. There is a need to train more technical support and graduate students. We cannot afford to lose people to other countries, as is happening now. More faculty positions are needed, and industry should support chairs.

Any university which hosts an AMS facility must commit support for a minimum of 10-15 years - faculty, graduate school, technical, logistical, secretarial. Similarly government (provincial or federal) must commit for the same period. Collaborative research is vital and interdisciplinary research should be encouraged. The national nature of any AMS facility demands inter-university collaboration and industry involvement.

More and better funding is needed for archaeology in general, especially for laboratory support. There is a need to educate users of AMS in good sample selection, as well as limitations, applications, complications and potential. In the short-term a booklet for users is desirable. In the longer term archaeology students should have more science training, especially at graduate level. An AMS laboratory needs a liaison person to interact with both physicists and chemists, and with geologists and archaeologists - a go-between expert.

Summary of perceived annual needs in Archaeology

Isotope	Now	Five Years Hence
^{14}C (Low Precision)	500	500
^{14}C (High Precision)	200	200
^{41}Ca		200
Totals	700	900

5. Report of the Working Group on Biomedical Science

Chair: Dr. D. Milton, Chalk River Laboratories, AECL

Current facilities cannot begin to support needed work in the biomedical sciences. For most purposes AMS analyses should be of low precision with high throughput, and for the envisioned demand no other instrumentation could substitute. Potential uses are studies in the following areas, all now currently underway at Livermore (California), though pioneered in Canada:

Xenobiotics	carcinogens environmental toxins
Metabolic studies	general metabolism metals, drugs
Diagnosis	body burdens epidemiology screening

AMS is particularly suited to experiments on people, because the high sensitivity obtainable permits the use of long lived isotopic traces with low radiation dose to the individual. The projected needs are as follows:

Isotope	Uses	Precision	Samples/Year
^{26}Al	xenobiotics metabolism diagnoses neurophysiology Alzheimer's ALS Guamosis Toxicity in Aluminium fabrication Aluminium in food and other consumer products	5%	5,000 - 10,000

^{14}C	xenobiotics metabolism diagnoses cancer carcinogens chemotherapeutics drugs	1 - 5%	5,000 - 10,000
^{3}H	same as ^{14}C	1-5%	5,000 - 10,000
^{41}Ca	metabolism diagnosis osteoporosis cell regulation/depth	5%	500
^{36}Cl	xenotoxins metabolic pathways PCBs	5%	300
^{32}Si	xenotoxins Alzheimer's	5%	100
^{79}Se	genotoxins	5%	100
^{129}I	thyroid	5%	100
Pt	diagnoses chemotherapy (cisplatin)	5%	100

The vast array of ^{14}C and ^{3}H labelled drugs and compounds available, including double-labelled pharmaceuticals, facilitates much of this work.

This work will demand a high-throughput, low precision machine, in a separate facility, not least because of the high levels of radioisotopes and the consequent risk of cross-contamination of dating samples. Presumably the funding should come from MRC, and later from the health industry. It should be a single integrated centralized facility, and will require considerable education and R&D in sample preparation. There is need for a champion and for liaison with the medical community, but once it takes off operating fees should be adequate for future expansion, especially as a diagnostic tool. Thus government

funding and university involvement are necessary at first, but ultimately this will be a routine, industry-funded, diagnostic tool.

For research purposes turnaround time can be as high 2-3 months, but once the machine evolves into a routine diagnostic tool this will need to be reduced to about 1 week.

Summary of perceived annual needs in Biomedical Science

Isotope	Now	Five Years Hence
^{3}H		10,000
^{14}C (Low Precision)		10,000
^{26}Al	200	10,000
^{32}Si		100
^{36}Cl	100	300
^{41}Ca		500
^{79}Se		100
^{129}I	200	200
Trace Elements		100
Totals	500	31,300

6. Report of the Working Group on Hydrology and Limnology

Chair: Dr. R. Andrews, Chalk River Laboratories, AECL

Present capacity for analyses is:

^{14}C	260 p.a.
^{36}Cl	100 p.a.
^{129}I	300 p.a.

The near-term demand is double these figures.

The small sample size needed for AMS greatly favours the use of this technique over competing methodologies of radiometry (for carbon) and neutron activation (for iodine). Competition among dating labs depends on price, turnaround time, quality.

AMS research is needed in hydrology for smaller samples, and extending range of isotopes. Accuracy should not be compromised for gains in throughput. User-pay facilities cannot always compete with subsidized facilities elsewhere.

In addition to existing facilities there should be a dedicated ^{14}C machine in Canada to meet growing needs in hydrology, environmental sciences and other fields, while greater research funding is needed in existing facilities to develop methodology for other isotopes.

Indeed there must be a base level of funding for R&D in AMS so that user fees no longer subsidized R&D, in order to maintain a leadership role.

Sample preparation must continue in existing facilities and amongst users, with the AMS laboratory providing expertise and assistance.

Regional aspirations are not an end in themselves, but aspirants must put forward their best cases and compete for funding. Economics and available personnel may dictate consolidated facilities. There is a worldwide shortage of AMS expertise, therefore very strong graduate programs are needed, associated with facilities, and this implies university commitment.

Universities should realize that AMS research has academic significance in itself while industry should support underlying research that could lead to techniques of value to them.

AMS needs a "home" for funding purposes - e.g. "applied science" or "analytical science", and not be left hanging out to dry as at present.

Summary of perceived annual needs in Hydrology and Limnology

Isotope	Now	Five Years Hence
^{14}C (High Precision)	500	500
^{36}Cl	200	200
^{129}I	600	600
Totals	1,300	1,300

7. Report on the working Group on Materials Characterization

Chair: Prof. J. D. Brown, University of Western Ontario

The essential areas of application of AMS in materials science include the ability to measure levels of several isotopes simultaneously at low concentrations in bulk specimens. Depth profiling is also essential. There is a need to develop a capability for mass scanning over a range of 50 to 100 mass units while rapidly switching from mass to mass for depth profiling. Little or no sample preparation is needed for this type of work.

There is a major need for R&D into AMS techniques, such as is now in progress at IsoTrace and North Texas.

This type of work requires a rather different machine from that needed for other disciplines (except economic geology) and AMS should expand into this field. At the moment it is impossible to predict what the ultimate demand for this kind of analysis will be, but no-one has ever over-estimated the need for analysis, and a demand of 10,000 analyses of trace elements may be expected to develop within a few years.

Once this kind of machine becomes a routine analytical tool for industry, as it should within a few years, turnaround time should be measured in weeks rather than months.

Any facility will require a strong research base and increased research personnel. This will necessitate direct funding for research, instead of using income from ^{14}C to subsidize research. A laboratory devoted to the needs of material science should be national, perhaps funded by industry and regional aspirations should have part in selecting the site.

The existing machine at IsoTrace should be redirected to this kind of research while a new machine should be built for ^{14}C dating.

Summary of perceived annual needs

Isotope	Now	Five Years Hence
Trace Elements		10,000

8. Report of the Working Group on Trace Elements in Economic Geology and Geochemistry

Chair: Dr. G. Wilson, Turnstone Geological Services Ltd.

This application is primarily of interest to geochemists and economic geologists who need to know the spatial distribution of (possibly valuable) elements at the background level in rocks and ores. Current capacity at IsoTrace includes the ability to analyze the follow trace elements on single polished crystals of electrically conducting minerals (e.g. sulphides) at the following detection levels, in count times of 100 seconds:

Au	100 picograms per gram
Ag	100 picograms per gram
Pt	1.5 nanograms per gram
Ph	3 nanograms per gram
Pd	20 nanograms per gram
Ir	30 nanograms per gram
Ru	120 nanograms per gram
Os	200 nanograms per gram

No other analytical technique can approach these sensitivities on such small samples.

Canadian capacity should be expanded, but for academic purposes there is no need for a second machine in Canada for this purpose. Current capacity in this area is about 300 analyses per year, and in the near future demand for academic analysis is likely to double. This is, however, an area where industry may create a major demand for simultaneous multi-element analysis, leading to the need for a machine dedicated to this form of analysis, as at North Texas, but for the moment commercial usage represents less than 50%.

This type of analysis demands certain precautions which may clash with other uses of a machine. For instance a separate ion source is certainly needed. Automation must be expanded and there is a need for the development of more reference materials used as standards. Research into surface charge compensation is also a high priority, so that non- conducting minerals may be analyzed.

User fees, at C$45-$90 per analysis (+ sample preparation), seem appropriate and not likely to restrict interest in the technique.

This is an area of AMS usage where collaboration between industry, university and government is particularly important.

Summary of perceived annual needs in Economic Geology and Geochemistry

Isotope	Now	Five Years Hence
^{129}I	100	100
Trace Elements	1,500	1,500
Totals	1,600	1,600

9. Recommendations of the International Participants

We acknowledge and highly commend the achievements and international reputation of the IsoTrace group at the University of Toronto in ^{14}C dating and the platinum-group element analyses, as well as their significant contribution to basic AMS research. All of these activities should be enhanced.

Our unanimous conclusions and recommendations are:

- Canada needs a new machine dedicated to ^{14}C analyses.

- We conclude and recommend that it would be most effective and appropriate to enhance proven performance if the new machine is located at IsoTrace, provided sufficient support is afforded by the University of Toronto.

- The existing facility should continue operation until the second new machine is fully operational, whereupon it should be upgraded.

  - To achieve this:

  - additional technical and scientific staff is necessary;

  - the position of the IsoTrace director (soon to fall vacant by retirement) must be filled quickly, with a researcher who will be dedicated to AMS research and will be a full-time member of Faculty;

  - another new academic position must be created (in addition to that occupied by the deputy director) to lead, under the director, an expanded ^{14}C scientific research program and to encourage collaboration between users and IsoTrace within the University of Toronto, both nationally and internationally;

  - additional sample pretreatment and target preparation facilities should be established using the acknowledged expertise of some of the existing analytical or radiometric ^{14}C laboratories elsewhere in Canada.

- Enhanced involvement in research endeavours of IsoTrace and collaboration by other faculties of the University of Toronto is essential.

- New educational programs and publications must be developed by IsoTrace to stimulate and guide Canadian AMS broadly based research. Canadian institutions must be made aware of AMS at IsoTrace.

- NSERC research grants should include and support the opportunity for samples to be analyzed by

AMS, if necessary outside of Canada, if requirements exceed the capacity available at IsoTrace, or if types of analysis are required which are not currently available there. The accumulation of such requests will stimulate the establishment of a second AMS centre elsewhere in Canada.

- Such an additional establishment is highly desirable.

- All existing radiometric ^{14}C dating laboratories in Canada, should, like the Geological Survey of Canada, the Saskatchewan Research Council and IsoTrace, participate in international Quality Assurance programs and exercise among themselves the strictest Quality Control. At the very least, quality control measures taken by each Canadian ^{14}C practitioner must conform to the internationally accepted norms as published in Radiocarbon.

- NSERC could suggest that the existing Board of Directors of IsoTrace, could be enhanced, if they consider it to be appropriate, by including non-Canadian AMS experts in an Advisory Committee to review progress in AMS and dating-related matters.

- NSERC, in collaboration with all Canadian institutions that have an interest in AMS and dating technologies, should periodically convene workshops related to those topics.

- The projected forth-coming demands for biomedical research utilizing AMS demands detailed consideration of the need for the establishment of a specialized facility devoted to this discipline alone.

- IsoTrace is currently capable of handling the demand for analyses in geochemistry and materials science, but the rapidly growing demand in these fields will soon lead to the necessity to establish a further new facility dedicated to these sciences.

M.Anthony	USA
J.Barker	UK
P.Damon	USA
D.Elmore	USA
W.Mook	Netherlands
H.Polach	Australia
J.Sisterton	USA

VII. Conclusions

General Recommendations from the Final Plenary Session

Needs

The international observers were anxious to ensure that the commanding lead in certain aspects of AMS shown by Canada should not be lost or further eroded by inadequacies of funding. Participants noted that some of the current equipment is rapidly reaching the end of its useful life and must be upgraded as soon as possible. This will require considerable expenditure.

There is clearly a great Canadian demand for more ^{14}C analyses, amounting in time to perhaps several thousand a year. Biomedical science users alone project up to 5,000-10,000 low precision analyses a year, while the need in oceanography and marine geology is likely to be around 2,000 high precision ^{14}C analyses p.a. Earth sciences, hydrology, archaeology, atmospheric sciences and environmental science all project higher numbers of analyses also.

Other isotopes where demand will far exceed capacity include ^{26}Al, ^{10}Be and ^{129}I, amongst others. In materials science and economic geology a need has been identified for rapid sequential multi-element analysis and profiling at sensitivities which are outside the range of other instrumentation.

Meeting the needs

These needs cannot be met by existing AMS facilities, even if they receive adequate funds for maintenance and operation (which they do not receive at the moment).

The projected needs can only be met by additional capacity. High precision ^{14}C analysis alone demands another machine in the near future to carry out both a heavy analytical load and further R&D into ^{14}C. (Such a machine should not, however, be technically limited to this isotope alone, but should be usable for certain other isotopes.) Experience in other countries has shown that the establishment of such a facility requires a lead time of four years.

The biomedical projections will also demand an additional specialized facility for this discipline alone.

Looking further into the future, the projected need for multi-element analysis and profiling in materials science and in economic geology will likewise require a specialized facility, which can only come about as a result of current R&D efforts at the Universities of North Texas and Toronto.

These initiatives can only succeed by collaboration between NSERC, MRC, SSHRC, certain federal government departments, universities, private industry and the Provinces, all of which must contribute in various ways, including financial support.

Every AMS facility should engage in AMS R&D, not merely in analysis per se, including basic research into understanding the physics and chemistry involved. In addition, every facility should be conducting research into applications, in close collaboration with users of the facility. The workshop participants recognized that such initiatives could not succeed without full participation from the institution which serves as the host for the facility, whether this be a university campus, a government research centre, or other. A long-term commitment to staffing and infrastructure from such an organization is essential. The host institution must also expect to be responsible for the civil engineering, buildings and services, including any necessary new construction.

Preparation Laboratories

The topic of facilities for pre-treatment and sample preparation created much discussion. The final consensus was that any AMS facility required an on-site peparation laboratory, which could serve both for routine preparation and also for Quality Assurance / Quality Control (QA/QC), but that under certain circumstances it may be advantageous to establish independent preparation laboratories in addition. For example, it is totally inappropriate to prepare high-level medical samples in the same laboratory that is used for samples with mere traces of ^{14}C, because of the danger of cross contamination. QA/QC, however, must always be directed by whichever facility must analyze the samples so prepared. Existing radiometric laboratories may perhaps be upgraded for this function.

User fees

Participants concluded that current user fees, which in Canada must cover the entire costs of sample preparation and analysis, are too high. Either user operating grants should be increased to reflect reality or AMS facilities should receive direct funding to subsidize the costs. Additional funding should be available to cover development of new AMS technology. As all other countries currently subsidize the cost of analyses, participants felt that the above policies would bring AMS in Canada in line with world practice.

Personnel

Participants noted the preponderance of greybeards amongst practitioners of AMS and a need for an infusion of younger blood. They therefore recommend that a major training effort be funded. This can best be done by providing funding for graduate students and post-doctoral fellows at existing facilities, including facilities outside Canada. It may also be necessary to recruit from outside Canada if significant expansion takes place as predicted. Increased staffing of existing

facilities (perhaps including that at McMaster University) is a priority, and should include increased faculty participation, as well as more research associates and technical staff. The former is the responsibility of the universities, but the latter should be funded by the governmental funding agencies.

Turnaround Time

For most purposes a turnaround time of 2-3 months seemed ideal, though four or even six months would often be acceptable. For materials science, however, and for medical diagnostics a turnaround time measured in weeks rather than in months seems to be essential. In addition, a shorter turnaround time is needed by graduate students, because of limitations on time posed by thesis schedules.

Funding

No one source of funds will be adequate for the expansion recommended in this report, but certain lead agencies and priorities can be identified.

Considerable additional funding will be required from NSERC in the first place, both to upgrade existing facilities (chiefly Mcmaster and Toronto Universities) and for an additional machine. Research groups should be encouraged to compete for funds for the provision of a new machine.

It will be the responsibility chiefly of MRC to fund a new machine for biomedical research, and again research groups should compete for the installation of such a facility, which will ultimately serve both for research needs and for diagnosis.

Universities, provincial and federal government research organizations and private industry must also be involved in funding equipment and research. Indeed, industry may be the chief source of funds for a machine and facility for materials science and economic geology, but such a facility should be publicly owned, not owned by a single company.

Reduction of user fees to a point where they reflect simply the cost of the analyses and do not subsidize research will necessitate greater funding for operational activities.

Current annual capacity (IsoTrace and Chalk River)

^{14}C (High Precision)	600
^{26}Al	100
^{36}Cl	150
^{129}I	300
Trace Elements	500

Summary of perceived immediate annual needs for AMS Analysis

Isotope	Earth Science	Oceanography	Archaeology	Bio-Medicine	Hydrology	Materials Science	Trace Elements	Totals
^{14}C (Low precision)			500					500
^{14}C (High precision)	1,000	1,000	200		500			2,700
^{10}Be	100	100						200
^{26}Al				200				200
^{36}Cl	100			100	200			400
^{129}I				200	600	100		900
Trace elements						1,500		1,500
Actinides	100							100
Totals	1,300	1,100	700	500	1,300	1,600		6,500

Summary of perceived annual needs five years hence

Isotope	Earth Science	Oceanography	Archaeology	Bio-Medicine	Hydrology Science	Materials Elements	Trace	Totals
^{14}C (Low precision)			500	10,000				10,500
^{14}C (High precision)	2,000	2,000	200		500			4,700
^{3}H				10,000				10,000
^{10}B	1,100	100						1,200
^{26}Al	1,000			10,000				11,000
^{32}Si		2,000		100				2,100
^{36}Cl	500			300	200			1,000
^{41}Ca			200	500				700
^{79}Se				100	600			700
^{129}I				200			100	300
Trace elements				100		10,000		10,100
Actinides	100	100						200
Totals	4,700	4,200	700	31,300	1,300	10,000	1,600	54,000

Appendices

Appendix A

Workshop Program

Monday, April 15

- *8:45 a.m.:* An overview of AMS Capacity, World-wide

Dr D.B. Carlisle	*Opening Remarks*
Prof W. Mook	*University of Groningen and The Netherlands Institute for Marine Research*
Prof D. Elmore	*Purdue University, Indiana*
Dr M. Anthony	*Texas Instruments, Dallas, Texas*
Dr J. Vogel	*Center for AMS, Livermore, CA*
Prof J. Barker	*University of Manchester, UK*
Dr H. Polach	*Australian National University*

- *Afternoon:* Discussion of Canadian Requirements

Brief Review of Canadian Capabilities and Potentials

Dr R.H. Andrews	*Chalk River Laboratories, AECL*
Prof A.E. Litherland	*IsoTrace Laboratory, Toronto*
Prof R.R. Johnson	*University of British Columbia*
Dr T.S. Lam	*University of Alberta*

Division into working groups according to subject areas

Tuesday, April 16

- *9:00:* Plenary Session

Presentation and discussion of the reports from the working groups

- *Afternoon:* Preparation of the Written Report

Appendix B: Working Group Terms of Reference

1. Within the area of expertise of your working group should AMS capacity in Canada be expanded or curtailed?

a) Estimate numbers of analyses per year for each isotope. Include explicit statement about possibilities of meeting these aims by methods other than AMS.

b) What is the turn-around time needed between submitting samples and obtaining results?

c) Do we need R&D into AMS itself?

d) What is the quality of the science a facility would support or serve?

e) What do you expect the competition to be for use of AMS within the research area of your working group?

2. How do we best achieve any recommended expansion of AMS?

a) for isotopes (such as ^{14}C) that need little development?

b) for isotopes (such as ^{244}Pu) where new methodological development is needed?

c) for R&D into AMS methodology?

d) for sample preparation?

e) How do we allow for regional aspirations: location, long-term university support, accessibility?

f) Personnel: availability of highly qualified personnel and managers; training.

g) Accessibility of facilities, breadth of use.

h) User fees.

i) Role of universities, government, industry.

Appendix C

Correspondence from those unable to attend the Workshop

Department of Archaeology
Simon Fraser University
Burnaby BC V5A 5S1

16 January 1991.

I have given your invitation to attend your workshop very considerable thought, but I'm afraid that I have come to the same conclusion as I did the last time you proposed to do this.

I am firmly of the belief that, if there are numerous Canadian researchers who want more AMS services, then they are the ones who should first sort out what their requirements are. It is only after the requirements of these researchers have been made entirely clear that it will be possible to work out the nature of the facilities that will be necessary to support those demands.

I honestly don't think that the Canadian research community will be well served by having a protagonist organize and orchestrate a meeting which I expect is a prelude to submission of a major grant request for a specific sort of lab and a specific type of machinery. That is putting the cart before the horse, and, at least on the surface, it seems to involve conflict of interest. I would think that it would be best to start with a clear understanding of the users' specific requirements for Canadian AMS facilities, such that mandates, responsibilities and supporting and reporting structures can be made clear to all.

The circumstances of an AMS service facility are much different from those of the accelerator laboratories of old, on which present organizational models seem to be based. In the old nuclear labs, the users' group was relatively small, well-defined and directly connected to the machinery itself. Reporting and responsibility were then relatively straight-forward, as they were mostly in-house. In contrast, AMS users are much more diverse, and the machinery itself is only of passing interest to them. Most have only a limited understanding of the method, and the use of the method is ancillary (if very important) to their prime research interests. Further, the AMS field is incredibly multi-disciplinary, and that seems to increase with every passing month. The fields of application now cover all three Canadian Research

Councils, and they are very disparate within each council's purview.

It is an unusual, complicated and confusing circumstance, and I believe it calls for some unusual (for Canada) responses. If Canadian researchers in Archaeology, Biology, Chemistry, the Earth Sciences, Geology, Medicine - want and need these services, let them make that clear and specify the requirements. To provide some structure, it would seem to me that the Interdisciplinary Committee at NSERC should go about taking charge of this organizational problem. I realize that by its nature, NSERC has a hard time acting (in distinction to re-acting) but I cannot believe that our administrators are so bound by their rules that whole fields must be trapped in them.

As I stated previously, if NSERC wishes to organize and call a broad meeting of users to discuss their requirements for AMS in Canada, I shall be happy to add my thoughts. Then we can try to sort out which machinery and structures will be required to provide these services. I don't think that is what is happening here, and so I must decline your invitation.

Since I suggest above that NSERC take on some responsibilities, I have sent a copy of this letter to the Program Director for Interdisciplinary Research.

Erle Nelson

Department of Geology
University of Toronto
Earth Sciences Centre

As you know, I and two of my students have been analyzing platinum group elements in base metal sulphide minerals from nickel deposits in China and Canada. These data are needed both to improve recoveries of these metals from the ores and to help understand how the deposits formed in nature.

The data that we have obtained so far have given us a new insight into the distribution of these elements in the individual minerals of certain of these ores. They have shown that except for Palladium in pentlandite, essentially all of the platinum metals are not distributed in the sulphides. This has been established by the unequalled low detection levels achievable with AMS.

Further work is needed:

i. to look at a broader spectrum of deposit types.

ii. to develop better spatial resolution (<0.1 mm) by being able to analyze a smaller area.

iii. to develop the capability of analyzing non-conductive minerals such as silicates. This will then allow us to use AMS as a tool for prospecting layered intrusions for platinum deposits.

In my view, the need for such analyses, and for improving the methodology is very important and ongoing into the foreseeable future. I hope you will be able to draw my comments to the attention of those attending the April 1991 AMS workshop in Burlington. I regret that other commitments prevent me from being there.

A.J. Naldrett

Lakehead University
Department of Geology
Thunder Bay
Ontario

As an IsoTrace user for about the past 5 years, I wish to underscore the value of this facility not only for my research in South America but also for my South American colleagues, with whom I participate in the "Quaternary Climates of South America International Geological Correlation Project" (IGCP -281). The data we have from IsoTrace has contributed significantly to our understanding of the Quaternary Climate History of Amazonia, and has provided, as well, new information for climate modellers regarding tropical climate boundary conditions during the last glacial cycle.

B.I. Kronberg

Montan-Universität Leoben
Institut für Geowissenschaften
Franz Josef Strasse 18
A-8700 Leoben
Austria

8 April 1991

Please accept my apologies for the delay in thanking you for your letter of 14 March, which reached me only on my return from a visit to Moscow. I had spent a week there to discuss cooperation with the Soviet Academy of Sciences (IGEM, Drs Genta and Distler) in the field of platinum geology.

It was with great excitement that we received the news that the IsoTrace facility is now on stream for the analyses of PGE in minerals. I have already followed your kind suggestion and, last Friday, dispatched a consignment of 8 samples for preliminary tests to your address.

The mode of residence of Platinum Group Elements in sulphides, tellurides, selenides and oxides is of greatest importance for many aspects of the mineralogy and genesis of PGE deposits. The question whether analytical PGE contents are present in individual mineral phases, or in the lattice of sulphides/oxides can only be resolved by AMS analysis.

Our PGE research group at Leoben is presently involved in the study of

platinum mineralization in the Duluth complex, Minnesota, in Alpine Ophiolites, and in Finnish stratabound complexes.

A cooperative project with the Soviet Academy of Sciences, studying deposits in the Urals is due to start in 1992.

Another important application of AMS is the distribution of gold in sulphides. We have at present two gold projects, one in New South Wales, Australia, and the other in Northern Ghana, West Africa. In both cases, the determination of gold in the ppb range in pyrite and arsenopyrite would be of great importance.

We have, for some time, considered your IsoTrace Laboratory as leader in the international effort in this field; thanks to the experience which you have already accumulated, you will very likely remain one of the few laboratories worldwide that one can turn to with problems like the above.

Let me conclude by saying that all members of our team would greatly appreciate the opportunity to cooperate with your Laboratory in the investigation of trace contents of precious metals in minerals.

E.F. Stumfl

Department of Energy
Environmental Measurements Laboratory
376 Hudson Street
New York, New York 10014-3621

11 January 1991

I want to thank you for the invitation you extended to me for participation in the Workshop on the Future Canadian Requirements for Accelerator Mass Spectrometry to be held in mid-April of this year. I was very gratified that you and your colleagues believed I could make a useful contribution to your discussions.

Unhappily, I will not be able to attend the meeting. Timing is unfortunate and other pressures argue that I attend to pressing matters here. In my absence, however, I would like you and the participants to know that, in my view, there is a growing cadre of U.S. researchers who view IsoTrace and its capabilities as a resource that should be unstintingly husbanded. This endorsement in no way detracts from the esteem we attach to U.S. facilities; it is simply a recognition of the present and future shortfall in AMS analysis capability that faces an increasing number of new, interested users. This will undoubtedly be intensified as facilities such as yours devise techniques to measure new tracers which will greatly expand the user community.

T.M. Beasley

Centre for Earth and Ocean Research
University of Victoria
Victoria BC

25 March 1991

Thank you for the information for the upcoming Accelerator Mass Spectrometry meeting at Burlington, Ontario. Unfortunately, I shall not be able to attend, but I would be most appreciative if you could keep me informed of the outcome.

My research on atmospheric hydrocarbons relies on ^{14}C measurements, currently being performed abroad. I would strongly support such a facility in Canada if capacity and accessibility could be afforded to a broad spectrum of users at reasonable analytical times and costs.

I wish you a successful meeting.

M.J. Whiticar

Appendix D

Correspondence received following the Workshop

Dept. of Earth Sciences
University of Waterloo
Waterloo, Ont. N2L 3G1

The span of Quaternary time dateable by ^{14}C is very small. In glaciated areas (most of Canada) the glacial substrate sets a lower limit on readily ^{14}C-dateable materials of about 13,000 years, and they may extend up to the present. Glacial cover generally diminished with time from 13,000 to 6,000 years ago.

Before 13,000 B.P., glacial cover existed back to about 23,000 B.P. and the prospects of finding organic deposits between those ages is generally nil or limited to the periphery of the ice sheet in northwestern Canada. Deposits of greater age within the ^{14}C dating range are encountered only rarely. Most older organic deposits are beyond the range of ^{14}C dating.

AMS ^{14}C dating has not fulfilled the early hopes of extended dating range. Its principle advantage is small sample dating. In most cases this has not proven very useful to Quaternary stratigraphy. The usual situation is having enough organics for conventional dating or not having any. In any case, conventional labs can be equipped cheaply to cover much smaller sample sizes, encroaching substantially on the AMS advantage.

For Quaternary geology, what is needed are new methods, applicable to new sample types, or extended dating range for various sample types, including organics. Til now, only a few grossly-underfunded individuals are experimenting with such methods as TL or ESR. It would be much more useful to Quaternary stratigraphy to devote financial resources to developing other methods than ^{14}C. I would be much happier to see a workshop organized to deal with the question "where do we go from here in Quaternary dating methods?" The present workshop is much too narrow.

The money being considered here for improvement and expansion of AMS would be a several-fold benefit spent on other dating methods, which are sorely needed in Quaternary stratigraphy. I realize AMS is of great use in archaeology, detailed study of postglacial climatic change, etc. but the new methods would also benefit those areas. Dating organics by radiocarbon has become "old hat". It's time to get on with other approaches.

P.F. Karrow

Dept. of Earth Sciences
University of Waterloo
Waterloo, Ont. N2L 3G1

14 May 1991

Thank you for your letter of April 23, which was waiting for me on my return from field work.

I am encouraged by what you say about AMS dating. I realize it is contamination that has been a major problem limiting the dating range and if this can be solved, wider application to Quaternary dating topics will result. Is there any possibility of combing with de Vries isotopic enrichment to devise an improvement?

I also realize AMS has important applications other than Quaternary geology and for those I really have no comment. It will be up to others to provide the enthusiastic support for advancement in those fields.

I look forward to seeing the Workshop report and wish you well in you endeavours.

P.F. Karrow

The University of British Columbia
Department of Oceanography
6270 University Boulevard
Vancouver, BC, V6T 1W5

May 1, 1991

Following the AMS Workshop on April 15th and 16th, 1991, I am writing to let you have a minority report from an oceanographic perspective on the requirements for AMS facilities in Canada. I am afraid that the report presented at the meeting was highly unsatisfactory, and did not reflect the depth and breadth of the need in this field. In spite of what the oceanography working group chairman said, I am also a practising oceanographer, with some knowledge of the use of this technique for solving oceanographic problems. I shall try to address the main questions that were considered, although I do not have the check-list of the questions posed to the working group chairmen.

1) Expansion of AMS Facilities

I believe there is an urgent need to expand AMS facilities in Canada. The main requirement in ocean sciences is for ^{14}C dating, but there are also needs for ^{10}Be and ^{26}Al. I noted the possibility that ^{32}Si could also be determined, because its half-life lies between those of ^{210}Pb and ^{14}C, this could constitute a very valuable additional radionuclide for obtaining chronologies in siliceous (biogenous silica) sediments.

The areas of the discipline that require this expanded capability include the following:

a) Late Pleistocene and Holocene sedimentation, where the need is to obtain chronologies and to check stratigraphies. Radiocarbon is the main need. Individual scientists often require high resolution profiles of radiocarbon assays, rather than individual dates. Hence, marine geologists and geochemists need a lot more machine time than some other users of AMS.

b) Global change research, often in collaboration with international programs. The most prominent of these are JGOFS (the Joint Global Ocean Flux Study) and WOCE (the World Ocean Circulation Experiment). These two programs will be collaborating closely in a 10-year research program aimed at understanding further the role of the ocean in climate change and ocean biogeochemical cycles, especially those of carbon. JGOFS will be carrying out the CO_2 program originally proposed by WOCE. The Canadian WOCE program has already started, and the Canadian JGOFS proposal is presently being review by the Collaborative Special Projects program of NSERC; a total of 67 scientists from the universities and government laboratories will collaborate in this research. There will therefore be a real need for a very substantial number of radiocarbon assays of dissolved and particulate organic materials from the ocean water column, and of sea floor sediments. This will represent the use for this nuclide both as a tracer and as a chronological tool. It is simply not enough to rely on the single dedicated facility for this work at Woods Hole.

c) The Ocean Drilling Program. Canaus, the Canada-Australia consortium, is a full contributing member of the international ODP. We regularly have Canadian participants on the drilling vessel, and there is a need for radiocarbon dating techniques in many of the geochemical and stratigraphic studies carried out on the samples obtained. There is presently discussion about an expansion of ODP facilities for global change research, so some of this endeavour will also fall under b).

Please note that the potential users of an expanded AMS capability include both university and government scientists.

2) Numbers of Analyses Required

This is very difficult to estimate. There is, of course, a basic need for a certain number of assays right now, but because many individuals are not using this

technique at the present time because of lack of adequate funding or because the present facilities are over-committed, there will also be an increased need if expanded facilities were available and they were accessible at minimum cost (see below). The figure of 2,000 radiocarbon assays p.a. given at the meeting is a reasonable estimate based on the population of oceanographers presently using the technique and potentially needing it in their research; I have estimated that there are 20-25 individuals falling into these two categories. In addition to radiocarbon, there is also a need for ^{10}Be and ^{26}Al measurements; perhaps 100 assays of each nuclide p.a. would suffice at the present time, but this could easily increase substantially. In addition, ^{32}Si measurements could also be used very fruitfully; it is not possible to specify the numbers here.

3) R&D Requirements

I believe there is a continuing need for R&D in all aspects of AMS. It was pointed out to us by Henry Pollach that the technique of conventional radiocarbon dating has been steadily improved over the years, and that there is little doubt that AMS will see the same kind of evolution. In addition to the need for continual development of AMS technology, I believe the urgent need at the present time is in the whole area of sample preparation and, in view of the sensitivity of the technique, research into strategies for targeting the particular phase, component or object one wishes to date. Some recent publications have shown how powerful is this latter approach. The sample preparation work should be carried out in close collaboration with the AMS team, or teams.

4) Quality of Science

This is a matter of personal judgement, but I think that the problems being addressed using this technique and the individuals pursuing the research are, in many areas, outstanding. Therefore, I think the science is of high quality.

5) Competition for Facilities

There is some competition for the use of facilities simply because they are insufficient. However, as I have indicated above, many people are putting off using the technique because of high costs and the long delays in getting results.

6) How to Achieve Expansion

There are two points to make. Firstly, I think that a second facility should be established. This should be a national facility and its establishment should be put out to competition. The successful bidders in this competition should be chosen on the basis of expertise, quality of local facilities and level of support at the local level. There should be no priority given to regional aspirations. Secondly, I believe that there should be a new dedicated radiocarbon facility established to satisfy the demands

principally from environmental scientists. In this way, the burden of providing large numbers of radiocarbon dates and of carrying out further AMS research (and following up on new applications, especially in medicine) could be handled somewhat more easily. I believe that user fees should be lowered substantially; I favour a facility fully supported with the necessary infrastructure funds to provide the necessary facility for joint research into the use of AMS. That is, I believe the best way to proceed is to have close collaboration between a researcher who needs access to the facilities and an AMS team.

Finally, in view of the need for a national facility, I think the proper sponsor for such an expansion of AMS facilities in Canada is the federal government, with appropriate support from the provinces and industry.

I hope these comments and opinions will be useful.

S.E. Calvert

Appendix D

List of Participants

Dr B.K. Afghan
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario, Canada L7R 4A6
Phone: 416-336-4661
Fax: 416-336-4989

Dr H.R. Andrews
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada KlJ 1JO
Phone: 613-584-3311x4116
Fax: 613-584-4024

Dr Mark Anthony
Texas Instruments Inc
PO Box 655936, MS-147
Dallas, Texas 75265 USA.
Phone: 214-995-3981
Fax: 214-995-5539

Dr J. Barker
University of Manchester
Department of Chemistry
Oxford Road
Manchester M13 9PL
United Kingdom
Fax: 011-44-61-2754598

Dr Steven Beneteau
Ontario Geological Survey
77 Grenville Street
llth Floor
Toronto, Ontario M7A 1W4
Phone: 416-965-1337
Fax: 416-963-3983

Dr Roelf P. Beukens
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-4628
Fax: 416-978-5848

Bonnie Blackwell
Department of Geology
McMaster University
1280 Main Street West
Hamilton, Ontario, Canada L8S 4L8
Phone: 416-526-6602
Fax: 416-528-3050

Dr Weston Blake Jr.
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario, Canada KlA OE8
Phone: 613-995-4583
Fax: 613-992-2468

Prof Jim D. Brown
Faculty of Engineering Science
Department of Material Engineering
University of Western Ontario
London, Ontario, Canada N6A 3K7
Phone: 519-679-2111 x.8332
Fax: 519-661-3808

Dr R.M. Brown
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada KOJ IJO
Phone: 613-584-3311
Fax: 613-584-4024

Dr S.E. Calvert
Department of Oceanography
University of British Columbia
Vancouver, B. C., Canada V6T IW5
Phone: 604-822-5210
FAX: 604-822-6091

Dr D.B. Carlisle
Environment Canada
Ottawa, Ontario, Canada K1A 0H3
Phone: 819-953-1551
Fax: 819-953-0461

Dr R.C. Carlisle
P.O.Box 3473, Station C,
Ottawa, Ontario, Canada K1Y 4J6
Phone & Fax: 819-682-5056

Dr J. Carron
Canada Centre for inland Waters
P.0.Box 5050
867 Lakeshore Road
Burlington, Ontario, Canada L7R 4A6
Fax: 613-336-4989

Prof C.S. Churcher
Zoology Department
University of Toronto
Toromto, Ontario, Canada M5S IAI
Phone: 416-978-3511
Fax: 416-978-8532

Barbara Conway
Cross-Disciplinary Activities Program
NSERC
200 Kent Street
Ottawa, Ontario, Canada KIA IH5
Phone: 613-996-6427
Fax: 613-992-5337

Dr R. Jack Cornett
Environmental Research
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada KOJ IJO
Phone: 613-584-3311
Fax: 613-584-4024

Richard Cresswell
IsoTrace Lab
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S IA7
Phone: 416-978-4041
Fax: 416-978-5848

Prof Paul E. Damon
Department of Geoscience
Isotope Geochemistry Laboratory
University of Arizona
Tucson, Arizona 85721 USA.
Phone: 602-621-6024

Dr Robert J. Drimmie
Environmental Isotope Laboratory
Department of Earth Science
University of Waterloo Waterloo,
Ontario, Canada N2L 3GI
Phone: 519-885-1211x2580
Fax: 519-888-4521

Prof David Elmore
Department of Physics
Purdue University
West Lafayette, Indiana 47907-1396
USA
Phone: 317-494-6516
Fax: 317-494-0706

Prof Ron M. Farquhar
Department of Physics
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-1810
Fax: 416-978-7606

Dr Clement Gariépy
Centre de Recherche en Geochimie Isotopique
et en Geochronologie (GEOTOP)
Université du Québec à Montréal
C.P. 8888, Succ. A
Montréal, Québec, Canada H3C 3P8
Phone: 514-987-4080
Fax: 514-987-3635

Muhammad Garwan
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-4041
Fax: 416-978-5848

Dr M. Gascoyne
Whiteshell Nuclear Research Establishment
Atomic Energy of Canada Limited
Pinawa, Manitoba, Canada ROE 1LO
Phone: 204-753-2311x2207
Fax: 204-753-2455

Bassam Ghaleb
Centre de Recherche en Geochimie Isotopique
et en Geochronologie (GEOTOP)
Université du Québec à Montréal
C.P. 8888, Succ. A,
Montréal, Québec, Canada H3C 3P8
Phone: 514-987-4080
Fax: 514-987-3635

Prof John Gray
Dept of Physics
University of Alberta
Edmonton, Alberta, Canada T6G 2E2

Professor Harry E. Gove
Nuclear Structure Research Laboratory
University of Rochester
Rochester, New York 14627 USA
Phone: 716-275-4943
Fax: 716-473-5384

Dr Fred Hopper
ARQM Section
Atmospheric Environment Services
4905 Dufferin Street
Downsview, Ontario, Canada M3H 5T4
Phone: 416-739-4866
Fax: 416-739-4521

Professor Richard Johnson
Department of Physics
University of British Columbia
Vancouver, B. C., Canada V6T 1W5
Phone: 604-222-1047
Fax: 604-222-1074

Dr Patrick J. Julig
Dept. of Sociology & Anthropology
Laurentian University
Sudbury, Ontario, Canada P3E 2C6
Phone: 705-675-1151x4207
Fax: 705-673-6519

Dr A. Kabir
Canada Centre for Inland Waters
P. 0. Box 5050
867 Lakeshore Road
Burlington, Ontario, Canada L7R 4A6
Fax: 416-336-4989

Prof R. Kerrich
Dept. of Geological Sciences
University of Saskatchewan
Saskatoon,
Saskatchewan, Canada S7N OWO
Phone: 306-966-5719

Dr W. E. Kieser
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-2241
Fax: 416-978-5848

Dr Linus R. Kilius
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-5724
Fax: 416-978-5848

Dr Vernon Kowslowski
Nuclear Physics Branch
Station 49
Chalk River, Ontario, Canada KOJ 1JO
Phone: 613-584-3311x4112
Fax: 613-584-4024

Prof T.P.A. Kruck
University of Toronto
Tanz Neuroscience Bldg.
6 Queens Park Crescent
Toronto, Ontario, Canada M5S 1A1
Phone: 416-978-1871
Fax: 416-978-1878

Dr Tsing Lam
Nuclear Research Centre
University of Alberta
Edmonton, Alberta, Canada T6G 2E2
Phone: 403-492-3637
Fax: 403-492-3408

Y. Lao
Atomic Energy of Canada Ltd.
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada KOJ 1JO
Phone: 613-584-3311
Fax: 613-584-4024

Willy Lennard
Dept of Physics
University of Western Ontario
London, Ontario, Canada N6A 3K7
Phone: 519-661-3283
Fax: 519-661-2033

Alice Leung
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S lA7
Phone: 416-978-2258
Fax: 416-978-5848

Prof A.E. Litherland,
Director, IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S lA7
Phone: 416-978-3785
Fax: 416-978-5848

Walter Lukiw
University of Toronto
Tanz Neuroscience Bldg.
6 Queens Park Crescent
Toronto, Ontario, Canada M5S IAI
Phone: 416-978-1871
Fax: 416-978-1878

Dr J. McKay
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0
Phone: 613-584-3311
Fax: 613-584-4024

Prof Don R. McLachlan
University of Toronto
Tanz Neuroscience Bldg.
6 Queens Park Crescent
Toronto, Ontario, Canada M5S lAl
Phone: 416-978-1871
Fax: 416-978-1878

Dr Roger McNeely
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario, Canada
KIA OE8
Phone: 613-995-4241
Fax: 613-992-2468

Prof Robert H. McNutt
Department of Geology
McMaster University
Hamilton Ontario, Canada L8S 4L8
Phone: 416-525-9140x2616
Fax. 416-546-9995

Prof A.R. Mermut
Dept of Soil Science
University of Saskatchewan
Saskatoon,
Saskatchewan, Canada S7N OWO
Phone: 306-966-6839
Fax: 306-966-6881

Prof Fred A. Michel
Department of Earth Sciences
Carleton University
Ottawa, Ontario, Canada KIS 5B6
Phone: 613-788-4400
Fax: 613-788-4490

Dr. Gwen Milton
Chalk River Laboratories
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada KOJ 1JO
Phone: 613-584-3311
Fax: 613-584-4024

Dr J.C.D. Milton
Atomic Energy of Canada Ltd.
Chalk River Laboratory
Chalk River, Ontario, Canada KOJ 1JO
Phone: 613-584-3311
Fax: 613-584-4024

Prof Ian Mitchell
Department of Physics
University of Western Ontario
London, Ontario, Canada N6A 3K7
Phone: 519-661-3393
Fax: 519-661-2033

Prof Dr W.G. Mook
Netherlands Institute for Sea Research
(NIOZ), P.O. Box 59
1790 AB den Burg, Texel
The Netherlands
Phone: 011-31-2220-19541
Fax: 011-31-2220-19674

Joseph P. Muller
Box 57165
Jackson Station
Hamilton, Ontario, Canada L8P 4X1
Phone: 416-525-1240

Marie-J. Nadeau
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-5685
Fax: 416-978-5848

Pat Ohlendorf-Moffat
293 Crawford Street
Toronto, Ontario M6J 2V7
Phone & Fax: 416-531-3339

Larry Pavlish
Department of Physics
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-5209
Fax: 416-978-5848

Dilette Polach
P. 0. Box 43
Garran ACT
Australia 2605
Phone: 011-61-6-281-2592
Fax: 011-61-6-249-0738

Dr H.A. Polach
P. 0. Box 43
Garran ACT
Australia 2605
Phone: 011-61-6-281-2592
Fax: 011-61-6-249-0738

Dr Ken Purser
Southern Cross Corporation
426C Boston Street
Topsfield, MA 01983, USA
Phone: 508-887-0028
Fax: 508-887-0031

Kevin R. Robertson
Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth,
Nova Scotia, Canada B2Y 4A2
Phone: 902-426-7731
Fax: 902-426-4104

Prof C.G. Rodrigues
Department of Geology
University of Windsor
401 Sunset Avenue
Windsor, Ontario, Canada N9B 3P4
Phone: 519-253-4232x2499
Fax: 519-973-7081

Prof John C. Rucklidge
Department of Geology
University of Toronto
Earth Sciences Centre
Toronto, Ontario, Canada M5S 3Bl
Phone: 416-978-2061
Fax: 416-978-3938

Professor Sherry Schiff
Department of Earth Sciences
University of Waterloo
Waterloo, Ontario, Canada N2L 3Gl
Phone: 519-885-1211
Fax: N/A

Prof H. Schwarcz
Department of Geology
McMaster University
Hamilton, Ontario, Canada L8S 4L8
Phone: 416-525-9140x4186
Fax: 416-528-3050

Dr J. Douglas Scott
Kidd Creek Division
Falconbridge Ltd.
P.0. Box 175, Suite 5000
Commerce Court
Toronto, Ontario, Canada M5L IE7
Phone: 705-235-7573
Fax: 705-235-7580

Prof Steve Scott
Department of Geology
University of Toronto
Earth Sciences Centre
Toronto, Ontario, Canada M5S 3Bl
Phone: 416-978-6554/5424
Fax: 416-978-3938

Dr Janet Sisterson
Cyclotron Laboratory
Harvard University
44 Oxford Street
Cambridge, MA 02138 USA
Phone: 617-495-2885
Fax: 617-495-8054

Dr S. Sood
Ontario Hydro
800 Kipling Avenue
Toronto, Ontario, Canada M8Z 5S4

Dr Vesna Sossi
TRIUMF
University of British Columbia
Vancouver, B. C., Canada V6T lW5
Phone: 604-222-1047
Fax: 604-222-1074

Dr Jan Terasmae
Department of Geography
Brock University
St. Catharines, Ontario, Canada L2S 3Al
Phone: 416-688-5550
Fax: 416-682-9020

Lucas Vela
Department of Chemical Engineering
University of Toronto
Toronto, Ontario, Canada M5S lAl
Fax: 416-978-8775

Dr G. Vilks
Atlantic Geoscience Centre
Bedford Institute of oceanography
P. 0. Box 1006
Dartmouth, Nova Scotia, Canada B2Y 4A2
Phone: 902-426-7735
Fax: 902-426-4104

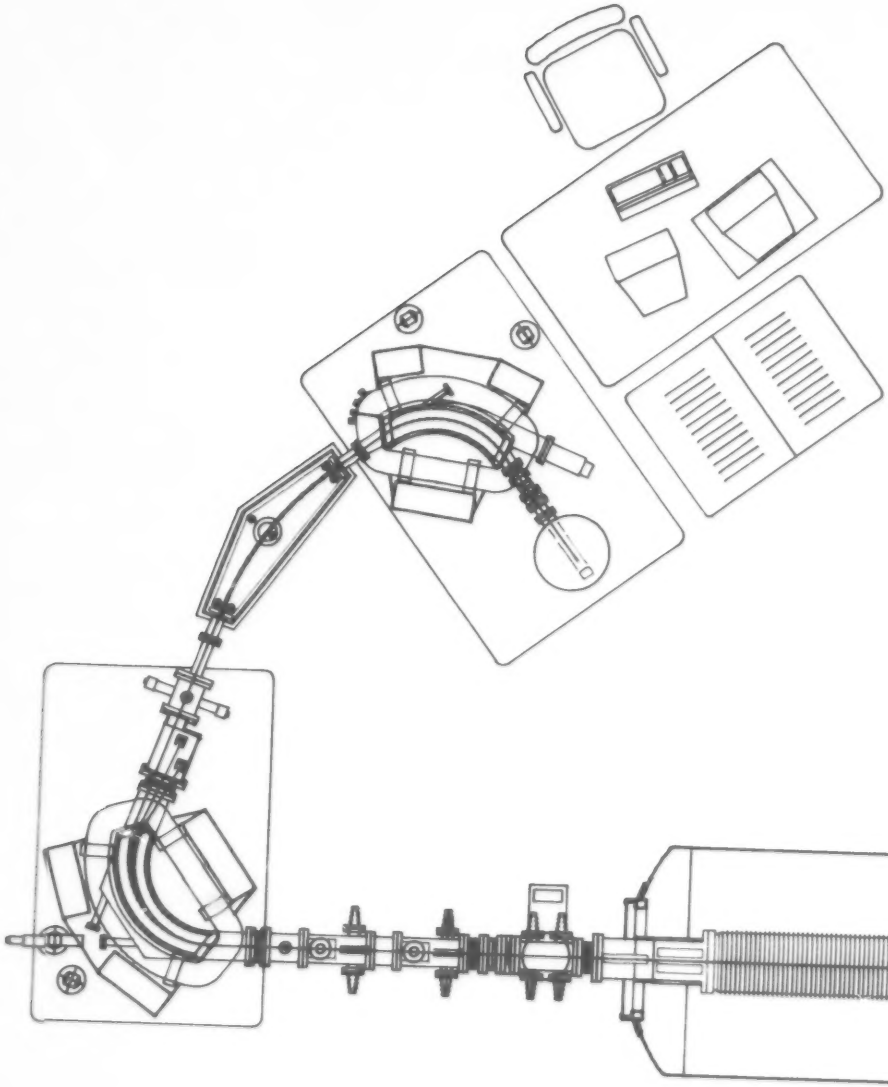
Dr John S. Vogel
Lawrence Livermore National Labs.
University of California
P.0. Box 808
Livermore, CA 94550, USA
Phone: 415-423-4232
Fax: 415-423-7884

Dr R.C.J. Wilkinson
Canada Centre for Inland Waters
P.0. Box 5050
867 Lakeshore Road
Burlington, Ontario, Canada L7R 4A6
Fax: 416-336-4989

Dr Graham C. Wilson
Turnstone Geological Services
P.O. Box 130
Station B
Toronto, Ontario, Canada M5T 2T3
Phone: 416-978-4041
Fax: 416-978-5848

Xiao Lei Zhao
IsoTrace Laboratory
University of Toronto
60 St. George Street
Toronto, Ontario, Canada M5S 1A7
Phone: 416-978-4041
Fax: 416-978-5848

Nadia Zupan
Department of Geology
McMaster University
Hamilton, Ontario, Canada L8S 4L8
Fax: 416-528-3050



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